Duke University Water Reclamation Pond
Methods

Auburn University Research Fellow:
Thomas Hogge
Visiting Assistant Professor

Auburn University Research Assistant:
Luis Loaiza
2021 MLA Candidate

Firm Liaison:
Evan Grimm
Senior Associate
Nelson Byrd Woltz Landscape Architects

Client Liaison:
Mark Hough
University Landscape Architect
Duke University

This investigation was conducted as part of the Landscape Architecture Foundation's 2020 *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*.

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

To cite:

Hogge, Thomas, and Luis Loaiza. "Duke University Water Reclamation Pond Methods." *Landscape Performance Series*. Landscape Architecture Foundation, 2020. https://doi.org/10.31353/cs1651

Table of Contents

Acknowledgements

The research team acknowledges the Coharie, Eastern Band of Cherokee Indians, Haliwa-Saponi, Lumbee, Meherrin, Occaneechi Band of the Saponi, Sappony, and Waccamaw Siouan peoples, whose lands include what is now known as North Carolina. We recognize these are ancestral lands of many Indigenous people who live and work in the region today.

We also recognize the Mvskoke (Muscogee Creek) nation, including the Abihka, Coosa, and Tallapoosa people and their descendants, whose lands were seized to create the territory known today as eastern Alabama and Lee County, on whose lands Auburn University was founded. And we acknowledge the Cheyenne and Arapaho of Upper Arkansas, the Kansas, Yo-lum-ne, Wo-wol, Co-ye-tie, Chu-nute, Yankton Sioux, Sioux (Wahpeton and Sisseton Bands), and Ya-wil-chine people, and 168 other tribal nations, who saw nearly 240,00 acres of lands in present day Kansas, California, Nebraska, Colorado, Iowa, Wyoming, Washington, Utah, South Dakota, Oregon, Montana, Minnesota, Arizona, Arkansas, and other states, seized and sold for over $4,400 in 1871 and 1872 to generate over $215,700 in endowment principal to fund Auburn University (Ahtone and Lee, 2020).

The team would like to also acknowledge and thank several individuals, who, as representatives of firms, departments, and institutions, graciously offered time, insight, information, and feedback that contributed to our understanding of the project's values and impacts on various public audiences. In particular, Mark Hough, University Landscape Architect, Duke University, connected us with various project team and University contacts and contributed a range of resources from his own efforts to integrate and highlight Duke Pond among the university's various water stewardship initiatives and educational mission; and Evan Grimm, Senior Associate, Nelson Byrd Woltz Landscape Architects, confirmed and clarified design intentions and provided project images and landscape construction documentation.

Also, James Caldwell, PE, McAdams Co, shared engineering design and construction documentation; Ryan Lavinder, PE, Duke Utility & Engineering Services, Casey Collins, PE, CEM, Energy Manager, and Stephen Carrow, Project Manager, Duke Facilities Management Department, shared project engineering and maintenance data; Dr. Curtis Richardson, Professor of Resource Ecology and Founding Director of the Duke University Wetland Center in the Nicholas School of the Environment, contextualized the project within the larger portfolio of stormwater management resources; Randy Neighbarger, Staff Assistant, Nicholas School of the Environment, expanded our understanding of social and educational programming at the Pond; Sara Childs, Duke Forest Director, and Judd Edeburn, former Director, clarified several aspects of the timber harvest that provided significant material and financial benefits for the project; Tavey McDaniel Capps, Sustainability Director for Sustainable Duke, coordinated survey distribution to the Duke University campus community; Alejandro Martinez, CIP, Associate Director for Duke University Campus IRB, reviewed survey content; and Brad Boone, project manager for Mid-Atlantic Infrastructure Systems, Inc, provided several other details about site demolition and earthwork.

Research Strategy

The research team set out to examine just one of several high-performance landscapes that comprise a watershed approach to stormwater management on the Duke University campus.

We used a variety of methods to examine the design features and analyze the performance aspects of the projects, including analysis of design drawings, secondary data collection, and digital surveys. Due to restrictions on site access as part of the University response to federal and state guidelines to limit impacts of the COVID-19 pandemic beginning in March 2020, on-site fieldwork was not possible within the case study timeline. We also relied on data from Duke Facilities Management Department, who tracks and analyzes water use at the Chiller Plant #2 nearly continuously, and also interpreted findings by various researchers at the Duke Wetland Center, whose ongoing monitoring has yielded significant data to help understand performance and change at the pond.

Modeled on the *Landscape Performance Series* (LPS) formatting, the case study summarizes the goals and benefits of the project, identifies sustainable features, challenges and solutions, cost comparisons, and both the scope of work for and lessons learned by the landscape architect. Due to the project's university and forest contexts, its educational and ecological goals are somewhat emphasized among social, and environmental benefits for local and regional stakeholders. Economic benefits are limited to impacts from environmental benefits. The research project is managed by the *Case Study Investigation* (CSI) program with funding support from a Landscape Architecture Foundation (LAF) grant.

Thomas Hogge, Research Fellow, was a lead designer for several major aspects of the project as a Senior Designer and Landscape Architect with Nelson Byrd Woltz Landscape Architects.

Environmental Benefits

Soil Creation, Preservation & Restoration

- ***Preserved 5,000 cu yds of alluvium and 2,700 cu yds of existing topsoil for re-use in pond planting installation. The total volume of reused soil is equivalent to 275,000 bags of organic topsoil, or 1 football field with a depth of nearly 4.3 ft.***

Background:
Durham County has a rich variety of soils, including Mecklenburg loam, White Store fine sandy loam, Conowingo silt loam, and Congaree silt loam. Pre-existing soil on-site consisted of White Store fine sandy loam (around 80%) and Congaree silt loam (20%). An inventory of pre-existing soils using the USDA Web Soil Survey is shown at Figure 01.

The pre-existing stream at the project site was heavily sedimented and its banks highly eroded. A geotechnical report prepared by Tai and Associates, PLCC used boring elevations based on topographic survey data by McAdams, Inc. to characterize the surface and subsurface conditions. A 3" to 8" thick layer of sandy-silty organic topsoil was encountered at the surface, and alluvial soil was excavated from 2'-6" to 9'-0" deep. Weathered bedrock was found at 0'-0" to 12'-6" depths. Much of the pre-existing soils were removed during construction to create sufficient volume for the new pond. The project removed 103,850 cy of degraded urban fill soil, or about 77% of the total volume of soil moved on-site (135,470 cy). Contractors used 23,000 cy of the removed degraded soil to build the pond dam. About 23% of excavated soil was reused on-site, especially in planting areas and other non-structural applications. The remainder was deposited as fill soil 1.6 miles away at a recreation field owned by Duke University.

Figure 01. Sandy loams were the predominant soil types at the Duke Pond site. Durham County Soils Map (USDA Web Soil Survey with site boundary overlay) showing the following soils: WsB (White Store sandy loam 2 to 6 percent slopes), WvC2 (White Store clay loam, 2 to 10 percent slopes, moderately eroded), WwC (White Store-Urban land complex. 0 to 10 percent slopes), PfE (Pinkston fine sandy loam, 10 to 25 percent slopes), WsB (White Store sandy loam, 2 to 6 percent slopes), MfE (Mayodan sandy loam 15 to 25 percent slopes), WsC (White Store sandy loam 2 to 6 percent slopes), Cc (Cartecay and Chewacla soils 0 to 2 percent slopes frequently flooded).

<u>Method</u>:
The research team was interested in quantifying both the quantity and quality of soils removed from and moved onto site. However, soil quality was not tracked by the construction team and therefore is not inventoried in this study (see Limitations). Quantities of soil removed and reused were provided by sitework contractor Mid-Atlantic Infrastructure. Volume conversions were calculated to provide additional physical context.

<u>Calculations</u>:

<u>Total preserved soil volume</u>
Volume of alluvium + Volume of topsoil = Total volume of preserved/reused soil

5,000 cy + 2,700 cy = 7,700 cy

Soil bag comparison conversion
Typical size of commercially available topsoil bag = 40 pounds (lbs)
40 pound (lb) bag of topsoil = 0.75 cf/bag topsoil
1 cubic yard (cy) = 27 cubic feet (cf)

Topsoil per bag (cy) = 0.75 cf of topsoil * (1 cy / 27 cf)
= 0.028 cy topsoil per bag

Number of bags of topsoil = Preserved soil (cy) / Topsoil (cy/bag)
= 7,700 cy / 0.028 cy/bag
= **275,000 bags of topsoil**

Football field comparison conversion
Area of soil on 1 football field (yds) = 53.33 yds W x 100 yds L = 5,333 sq.yd.
Height of preserved soil on field (ft) = Volume on field (cy) / Area of field (sq.yd.) * 3 ft / 1 yd
= 7,700 cy / 5,333 sq.yd. * 3 ft / 1 yd
= 1.444 yds * 3 ft/yd
= 4.33 ft depth

Sources:

Brad Boone, Project Manager at Mid-Atlantic Infrastructure Systems, Inc, email to Auburn University research team, June 2020.

Davis, William Anderson. 1920. "North Carolina Maps." University of North Carolina at Chapel Hill. https://dc.lib.unc.edu/cdm/ref/collection/ncmaps/id/309.

Tai and Associates, PLLC. 4 May 2012. Subsurface Exploration Report. Raleigh, North Carolina.

USDA Web Soil Survey. 2020. "Durham Soil Map." USDA Natural Resources Conservation Services. Accessed at https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

Limitations:

Soil volume data were supplied by the sitework contractor and did not distinguish specific soil types or record specific quality of removed or imported materials. Some topsoil was imported but a record of the amount was not available. Data were not independently verified by the research team. Soil quality testing was not recorded for pre-existing soils. Pre-construction geotechnical data described soil character and composition but not mineral or chemical attributes.

Stormwater Management

- ***Stores 16.4 million gallons of stormwater at normal pool elevation, equivalent to 25 Olympic-sized swimming pools. At maximum capacity, the pond holds 31.8 million gallons, equivalent to 48 Olympic-sized swimming pools.***

Background:
The pond stores reclaimed stormwater primarily to supply the Duke University Chiller Plant #2. As of this case study reporting, the pond is the only example among university campuses (known to the research team and Duke University) of a stormwater pond used to not only manage stormwater but also supplement chilled water supply. Stormwater ponds at University of Virginia (Charlottesville VA) and Furman University (Greenville SC) are not used for chilled water plant (CWP) supply, and the WaterHub at Emory University (Atlanta GA) is not a retention pond but does support the campus CWP with a 50K gallon reserve of reclaimed stormwater. At normal pool elevation (+311'-0"), pond capacity is 16.4 million gallons. Pond surface elevation at the 500-year storm is 319'-0". The total volume of the pond from +301'-0" (bottom of pond) to +320'-0" (top of dam) is 4,258,338 cf. The pond can supply the chiller plant for up to two weeks during a worst-case water shortage. Depending on time of year and seasonal demand the supply could be greater for longer, especially in a drought scenario, which would be quite complex: drought is typically defined in weeks and without rain filling it, the pond may be strained for usable water before the drought actually starts.

Method:
Duke Facilities Management Department (Duke FMD) provided benchmark pond storage capacities, which were supplemented by interviews with project designers and engineers.

Calculations:

Pond capacity conversion
Volume of pond (gal) at +311'-0" (normal elevation) = 16,400,000 gal
1 cf water = 7.48052 gallons
Volume of pond (cf) at +311'-0" = 16,400,000 gal * (1 cf / 7.48052 gal)
= 2,192,361.1 cf capacity

Volume of pond (cf) at +320'-0" (maximum elevation) = 4,258,338 cf
Volume of pond (gal) at +320'-0" = 4,258,338 cf * (7.48052 gal / 1 cf)
= 31,854,582.6 gallons

Pool comparison conversion
Olympic-sized swimming pool dimensions = 50 m L, 25 m W, 2m D (USA Swimming)
1 meters (m) = 3.28084 feet (ft)

a. 50 m * (3.28 ft / 1m) = 164.042 ft
b. 25 m = 82.021 ft
c. 2 m = 6.56168 ft

Pool volume (cf) = a * b * c
= 164.0 ft * 82.0 ft * 6.6 ft
= 88,756.8 cf

Pond volume (pools) at +311'-0" (normal elevation) = 2,192,361.1 cf / 88,756.8 cf
= 24.7 swimming pools

Pond volume (pools) at +320'-0" (maximum elevation) = 4,258,338 cf / 88,756.8 cf
= 47.9 swimming pools

Sources:

Curtis Richardson, PhD, Director; Neal Flanagan, PhD; and Mengchi Ho, PhD. 2019. Duke Pond Water Quality and Nutrient Budget Progress Report, Fourth Annual Report (2018 Monitoring). Durham: Duke University Wetland Center.

USA Swimming. Pool Dimensions and Recommendations. Accessed at https://www.usaswimming.org/docs/default-source/clubsdocuments/facilities/pool-certifications/pool-dimensions-and-reccomendations.pdf

Stephen Carrow, Project Manager at Duke University Facilities Management Department, in email to Auburn University research team, June 2020.

Limitations:

Pond volume is estimated based on designed capacity and does not factor in the continuous and dynamic processes of erosion and sedimentation that cause minor changes in the profile and area of the pond, and more major changes in its base elevation and volumetric capacity. The pond has not been dredged and bottom-of-pond elevations were last measured in 2017. Duke FMD anticipates taking new measurements in 2020-2021, and that these will indicate dredging is required to re-establish the designed capacity.

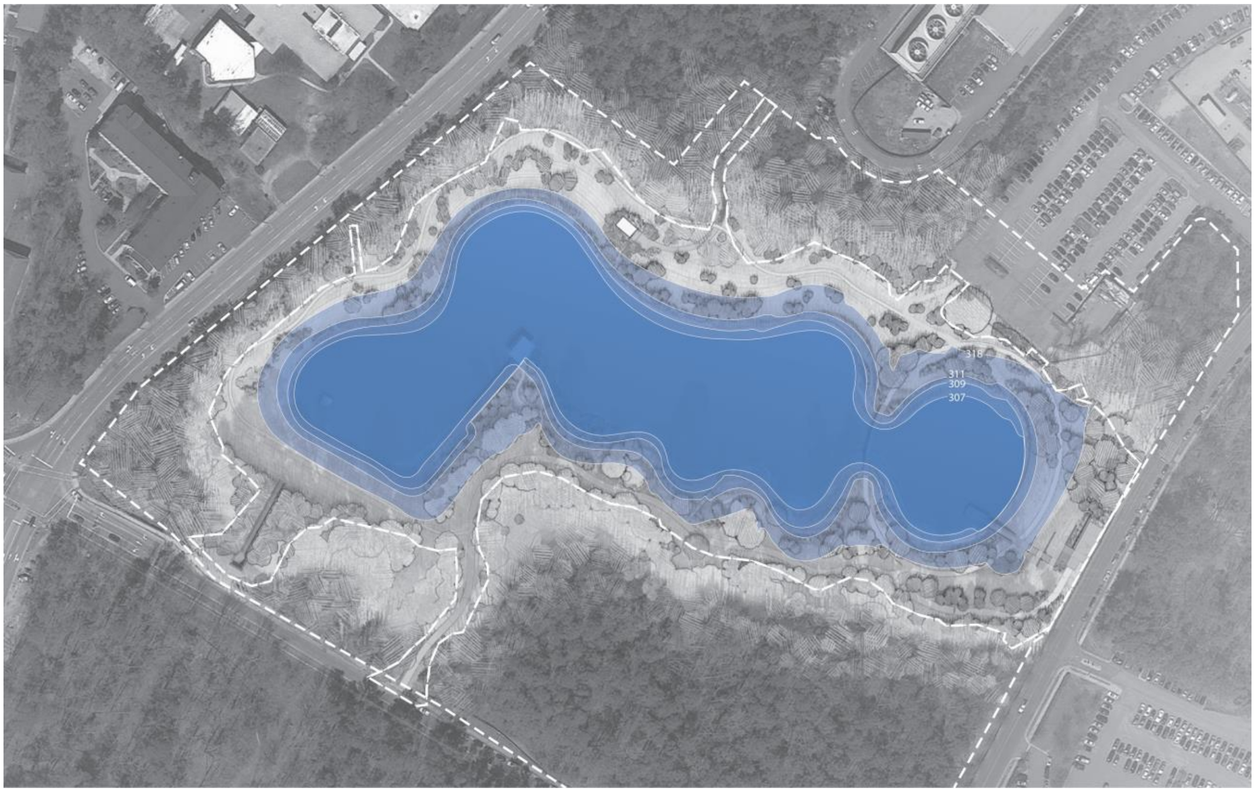


Figure 02. Pond water levels diagram (Overlays on illustrative plan from Nelson Byrd Woltz Landscape Architects)

Water Conservation

- ***Provides 85-90 million gallons of reclaimed stormwater per year, fulfilling 16% of the university's overall annual potable water demand. This reduces dependence on potable water and saves approximately $400,000 per year. Projections suggest that the water savings alone will cover the cost of the project by 2025.***

Background:
The design and engineering teams calibrated the pond to supply the Chilled Water Plant (CWP) with over 100 million gallons annually but complexities due to filtration, water quality, and variables of rainfall, among others, reduce the possible draw. The maximum potable water demand for the university was over 645 million gallons in 2006, and 449 million gallons in 2010. In 2015, the year of project completion, the pond provided almost 20 million gallons, whereas from 2016 to 2019 it supplied almost 90 million gallons annually.

Duke FMD estimates that the project has saved an estimated total of $2.1 million in potable water fees in the first five years since its completion in 2015. With projected future demand estimated at 180 million gallons per year (Duke FMD), drawing half of this water from the pond -- the average annual estimated pond withdrawal -- is anticipated to save $2.3 million per year..

Duke University is billed as a Tier 3 user (5-8 CCF per month) by the City of Durham. Tiered rates reward customers who use less water by charging the lower rates for water used in the lower tiers. Tier 1 users consume 0-2 CCF monthly; Tier 5 consumes over 15 CCF monthly.

Method:
Duke FMD provided water use data to the research team, which was verified by the research team using water unit cost data from Durham County. The research team compared the calculations to the provided estimates of total University water use.

Duke FMD tracks water use across campus and provided analysis of historic potable and alternative water use and annual unit cost data to the research team. In Figure 03, Alternative Water Use includes the pond, reclaimed condensate from the chiller plant operation, and any rainwater that falls on the roof of the Chiller Plant (Duke FMD). Using Duke University's status as a Tier 3 customer of the City of Durham Water and Sewer, the team used the Total Campus Water Use data (see Figure 03) to determine water volumes and associated costs of potable and nonpotable water use.

Calculations:

Abbreviations
Mgal = one million gallons
CCF = one hundred cubic feet
MCF = one thousand cubic feet

Water use reduction
Average water use, Mgal (see Table 01):
2016 = 540; 2017 = 570; 2018 = 601; 2019 = 609
Average (2016-2019) = Total (Mgal) / 4
= (540 + 570 + 601 + 609) / 4
= 580 Mgal

Average water volume (Mgal) drawn by CWP = 90 Mgal (see Table 01)
Percent water demand = (Volume drawn by CWP, Mgal * 100%) / (Average water use, Mgal) =
= (90 Mgal * 100%) / 580 Mgal
= 15.5%

Potable water use

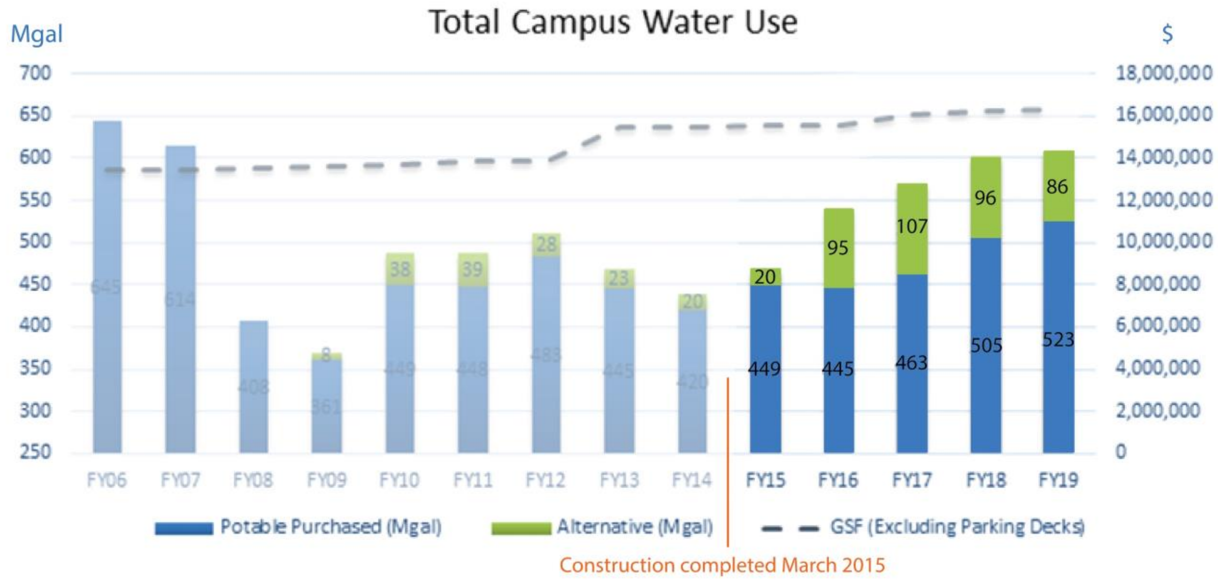


Figure 03. Total Campus Water Use (Source: Duke University Facilities Management Department). Chart modified to indicate water quantities and construction completion date.

Confirming annual water savings reported by Duke FMD
Average annual water cost savings, reported ($) = **$400,000.00**
Average annual water use savings, reported (Mgal) = 96 Mgal

Local water costs by year for average
City of Durham, monthly water unit costs, FY14-FY21 ($/CCF):
FY14 - $2.88; FY15 - $2.92; FY16 - $3.00; FY17 - $3.10;
FY18 - $3.19; FY19 - $3.22; FY20 - $3.30; FY21 - $3.35
Average water unit cost ($/CCF) = Water unit cost, FY15-21 ($/CCF) * / Years, FY15-21
= $(2.92+3+3.10+3.19+3.22+3.30+3.35) / 7
= $22.08 / 7
= $3.15 CCF / year

Average local water cost savings
Average annual water cost savings ($) = Water use savings (CCF) * Average water unit cost ($/CCF)
= 128,342.25 CCF * $3.15/CCF
= $404,278.08

These calculations confirm the water cost savings estimate of $400,000 provided by Duke FMD.

Annual cost per use

		2016	***2017***	***2018***	***2019***	***Total (2016-2019)***	***Average (Total / 4)***	***%***
a.	***Annual pond water use (Mgal)***	*540*	*570*	*601*	*609*	*2,320*	*580*	*100%* *(a/a)*
b.	***Annual pond water use (MCF)***	*70.2*	*74.1*	*78.13*	*79.17*	*301.6*	*75.4*	
c.	***Annual potable water purchased (Mgal)***	*445*	*463*	*505*	*523*	*1,936*	*484*	
d.	***Annual alt water use (Mgal)***	*96*	*107*	*96*	*86*	*385*	*96*	
e.	***Potable total annual cost (US$M)***	*$12.6*	*$13.2*	*$14*	*$14.1*	*$54.04*	*$13.5*	
f.	***Alt Mgal cost (US$M) (e*f)/a***	*$2.2*	*$2.5*	*$2.2*	*$2.0*	*$8.9*	*$2.2*	
g.	***Total Pond water use cost (US$M) (b/100)*c***	*$2.1*	*$2.3*	*$ 2.5*	*$ 2.55*	*$ 9.4*	*$ 2.4*	
h.	***Pond use (Mgal) (h*e)/g***	*90.41*	*98.61*	*106.99*	*109.44*	*405.45*	*101.36*	*17.48%*

Table 01. Annual Cost per Use (Values extracted and interpolated from Total Campus Water Use chart provided by Duke FMD. See below for calculations)

<u>Cost per use calculations for breakeven analysis</u>
Values are represented in the Total Campus Water Use chart provided by Duke FMD (Figure 03) and described below to support calculations.

a. <u>Total annual pond water use, by year (Mgal)</u>
2016 = 540; 2017 = 570; 2018 = 601; 2019 = 609

Average annual pond water use, 2016-2019 (Mgal) = Total use / Years
= (540 + 570 + 601 + 609) / 4
= 580 Mgal

Rate of pond water use (%) = Average alternative water use / Total water use * 100

= 96 Mgal / 580 Mgal * 100
= 0.1655 * 100
= 16.55%

b. <u>Total annual pond water use, by year (MCF)</u>
2016 = 70.2; 2017 = 74.1; 2018 = 78.13; 2019 = 79.17

Average annual pond water use (MCF) = Total use, 2016-2019 / Years
= (70.2 + 74.1 + 78.13 + 79.17) MCF / 4
= 75.4 MCF

c. <u>Potable water purchased, by year (Mgal)</u>
2016 = 445; 2017 = 463; 2018 = 505; 2019 = 523

Average water purchased (Mgal) = Total purchased (Mgal) / Years
= (445 + 463 + 505 + 523) /4
= 484 Mgal

Potable water purchased from Durham County provides water for campus use well beyond the Chiller Plant use that the pond supports.

d. <u>Alternative water use, by year (Mgal)</u>
Alternative water use is mostly attributed to withdrawals from the pond. Total alternative use from 2009, the first year alternative use was recorded, to 2015, the year pond construction was completed, is used to establish a benchmark for use not attributed to the pond. Quantities are derived from Figure 03 but, as reported by Duke FMD and noted at Background, alternative use from 2016 and later is mostly from pond withdrawal.

Average alternative water use, 2016-2019 (Mgal) = Total use / Years
= (95 + 107 + 96 + 86) / 4
= 96 Mgal, 2016-2019

Average alternative water use, 2009-2015 (Mgal) = Total use / Years
= (8 + 38 + 39 + 28 + 23 + 20 + 20) / 7
= 25.14 Mgal, 2009-2015

e. <u>Total annual water use cost (US$M)</u>
Values interpolated from Figure 03.

2018 Water use (Mgal) = 601
2018 Annual water cost (US$M) = $14M

Year (Annual water use, Mgal) * 2018 Annual cost) / 2018 Water use (Mgal) =

Annual water cost (US$)

2016 (540 Mgal * $14M) / 601 = $12,579,034.94
2017 (570 Mgal * $14M) / 601 = $13,277,870.22
2018 (601 Mgal * $14M) / 601 = $14,000,000.00
2019 (609 Mgal * $14M) / 601 = $14,186,356.07
Total annual water cost, 2016-2019
(US$M) = $54,043,261.23

Average annual water cost, 2016-2019 (US$M) = Total annual cost / Years
= $54.0M / 4
= $13,510,815.31

f. Annual Alternative water cost
Values interpolated from Figure 03.

*(Alternative water used (Mgal) * Annual cost)/Total Mgal*
2016 (95 Mgal * $12.6M)/540 = $2,212,978.37
2017 (107 Mgal * $13.2M)/570 = $2,492,512.48
2018 (96 Mgal * $14M)/601 = $2,236,272.88
2019 (86 Mgal * $14.2M)/609 = $2,003,327.79

Total annual alternative water cost 2016-2019 (US$M) = $8,945,091.51

Average annual alternative water cost 2016-2019 (US$M) = Annual cost / Years
= $8.9M / 4
= $2,236,272.88

g. Total Pond water use cost ($) (Total Annual Pond Water use, Mgal/100) * Water unit cost
2016 (70.2M/100)*3.00 = $2,106,000.00
2017 (74.1M/100)*3.10 = $2,297,100.00
2018 (78.1M/100)*3.19 = $2,492,347.00
2019 (79.2M/100)*3.22 = $2,549,274.00

Total annual Pond water use cost 2016-2019 (US$M) = $9,444,721.00

Average annual Pond water use cost 2016-2019 (US$M) = Total annual use cost / Years
= $9.4M / 4
= $2,361,180.25

h. Pond water use Mgal (Pond Mgal cost * Alt Mgal) / A Mgal cost
2016 ($2.1M * 95) / $2.2M = 90.41
2017 ($2.3M * 107) / $2.5M = 98.61

2018 ($2.5M * 96) / $2.2M = 106.99
2019 ($2.6M * 86) / $2.0M = 109.44

Total pond water use 2016-2019 (Mgal) = 405.45 Mgal

Average pond use 2016-2019 (Mgal) = Total pond water use / Years
= 405.45 Mgal /4
= 101.36 Mgal

Project payoff based on water cost savings
The CSI research team calculated a "break-even" point for the project, at which total water cost savings equal the total project costs. This calculation uses local water costs to extrapolate from Duke FMD data and confirm estimates based on historical data using an average water cost (A) and on future savings using a periodic growth-rate projection (B) that presumes water costs will continue to increase in the future.

Projected average annual demand, reported (Mgal) = 180 Mgal

Projected average annual water cost, ($) = Cost, current ($) * (1+i)^n
i = growth rate
n = period
Water unit cost rate increases, year-to-year (from Local water costs by year, above).
2014-15: 1.4%; 2015-16: 2.7%; 2016-17: 3.0%; 2017-18: 2.9%; 2018-19: 1.0%; 2019-20: 2.5%; 2020-21: 1.5%

Average historic growth rate (i) = Total growth rates / Years
= (1.4%+2.7%+3.0%+2.9%+1.0%+2.5%+1.5%) / 7
= 2.14%
n = 5 years

The growth rate (i) is projected for FY22-27 based on the Average Water unit cost rate increase for FY14-21.
i = 2.14%

(A) Simple payoff period (years) = Project cost ($) / Water cost savings ($)
= $11,000,000 / $404,280
= 27.2 years

Projected future average annual water cost, ($) = Savings, current ($) * (1+i)^n

(B) Projected payoff period (years) = Water unit cost ($) * (1+i)^n

($) = $3.13/CCF * (1+0.0226)^5
= $3.74/CCF

Sources:

Curtis Richardson, PhD, Director; Neal Flanagan, PhD; and Mengchi Ho, PhD. 2019. Duke Pond Water Quality and Nutrient Budget Progress Report, Fourth Annual Report (2018 Monitoring). Durham: Duke University Wetland Center.

City of Durham. Current Water & Sewer Rates. Accessed at https://durhamnc.gov/1040/Current-Water-Sewer-Rates

Holmes, D. (15 August 2018). Nelson Byrd Woltz Landscape Architects turns infrastructure into place-making with Duke Pond. Retrieved from World Landscape Architect: https://worldlandscapearchitect.com/nelson-byrd-woltz-landscape-architects-turns-infrastructure-into-place-making-with-duke-pond/

Ryan Lavinder, Civil Engineer at Duke Utility & Engineering Services Facilities Management Department, provided in email to Auburn University research team, March 2020.

Welton, J. (24 June 2016). Duke Pond in Durham: Function in disaster, finish in style. Retrieved from The News & Observer: newsobserver.com/entertainment/arts-culture/article85549482.html

Limitations:

Final pond volume and University water-use data was provided and not independently verified by the research team. The research team was not able to conduct outflow rate sampling on-site during the CSI schedule due to pandemic-related travel restrictions and so relied on provided historic data.

Values are estimated from 2014-2019 data provided by Duke FMD and were not independently verified by the research team. Alternative non-potable water uses are not categorized separately to make clear how much water use savings can be attributed directly to the pond construction and the associated water drawn by the CWP.

Water Quality

- ***Reduces total nitrogen by 30-100%, phosphorus by 11-100%, and total suspended solids by 77-100% during typical storms when comparing the water flowing into and out of the pond.***

Background:

Erosion and sedimentation of the pre-existing stream channel were major water quality issues and contributing factors for floods during storm events. The pond addresses upstream sedimentation at the forebay, where water is slowed enough to drop sediment, which is retained in the forebay by weir walls located under the forebay bridge. Sediment can be excavated during routine maintenance of the pond. Duke FMD has not dredged the pond since construction but anticipates doing so in 2020-21.

Nitrogen is a nutrient necessary for plant growth. However, an excess of nitrogen in water or soil can be toxic for flora and fauna. Phosphorus usually helps with fertilization. High levels of nitrogen and phosphorus reduce the amount of oxygen in the water and affect the vitality of wetland vegetation.

Method:
Duke University Wetland Center (DUWC) has gathered data on soil, water, and plant health since project completion. Several graduate students at the Nichols School of the Environment have used the pond as a research site. Nitrogen, phosphorus, and sediment are measured at several points in the pond and compared to evaluate performance. Nitrogen loading is based on comparison of nutrient mass balance from several samples over time. Below, nutrient mass balances of Unfiltered Total Nitrogen (UTN), Unfiltered Total Phosphorus (UTP), and Total Suspended Solids (TSS) during several storm events in 2015-2019 are expressed in DUWC Monitoring Reports as the difference between influent and effluent loads as a percentage of influent load.

Calculations:

Reduction of nutrient mass balances

Storm event (Date)	Unfiltered Total Nitrogen % difference (UTN)	Unfiltered Total Phosphorus % difference (UTP)	Total Suspended Solids % difference (TSS)
11/07/2015	63	71	98
02/15/2016	30	11	92
10/07/2016	28	28	77
12/04/2016	66	74	97
03/13/2017	99	98	99
08/31/2017	99	99	99.8
02/04/2018	68	85	94
10/11/2018	58	73	92
07/04/2019	100	100	100
07/05/2019	56	80	90
Total	667	719	938.8

Average reduction of Nitrogen (%) = Total reductions measured / Storm events
= 667 / 10
= **66.7%**

Average reduction of Phosphorus (%) = Total reductions measured / Storm events
= 719 / 10
= **71.9%**

Average reduction of Total Suspended Solids (%) = Total reductions measured / Storm events
= 938.8 / 10
= **93.88%**

<u>Sources</u>:

Curtis Richardson, PhD; Neal Flanagan, PhD; Brooke Giuliano, MEM. May 2015. Chiller Pond Data Collection Progress Report, Report 1. Durham: Duke University Wetland Center and Nicholas School of the Environment.

Curtis Richardson, PhD; Neal Flanagan, PhD; Brooke Giuliano, MEM; and Mengchi Ho, PhD. May 2016. Chiller Pond Data Collection Progress Report, Second Report. Durham: Duke University Wetland Center and Nicholas School of the Environment.

Curtis Richardson, PhD; Neal Flanagan, PhD; and Mengchi Ho, PhD. December 2017. Duke Pond Water Quality and Nutrient Budget Progress Report, Third Report. Durham: Duke University Wetland Center.

Curtis Richardson, PhD; Neal Flanagan, PhD; and Mengchi Ho, PhD. August 2019. Duke Pond Water Quality and Nutrient Budget Progress Report, Fourth Annual Report (2018 Monitoring). Durham: Duke University Wetland Center.

<u>Limitations</u>:

Values are referenced from water quality monitoring data acquired by the Duke University Wetland Center and Nicholas School of the Environment. Water quality measurements from 2019 are not available, and the research team was not able to conduct sampling on-site in 2020 during the CSI schedule due to pandemic-related travel restrictions.

Flood Protection

- ***Reduces flooding impacts by storing and slowing runoff from up to a 24-hour, 500-year storm event. The overall outflow rate of the 10-year storm was reduced by 720 cfs or 40% compared to pre-construction design storm estimates.***

Background:
The pre-existing stream was highly degraded and had near-zero capacity for retention and storage of runoff during storm events of any size or duration. The stream and low lying area between Circuit Drive and Towerview Drive often flooded prior to construction of the pond. There was no risk of flooding campus buildings, but there was increased risk of road failure associated with the undersized culverts. The more direct impact of the pond on flood reduction e.g. reduction in flood events was not able to be verified or quantified in a meaningful way by the research team beyond anecdotal observations from Duke FMD.

The designed pond can pass a 500-year storm, equivalent to 1/3 PMP (probable maximum precipitation), or 10" of rain in six hours.

Method:
Stormwater management of the site was designed to manage runoff during a 24-hour, 500-year storm event. Duke FMD records flow rate for the pond with three probes detecting the inflow, base flow, and outflow of the pond.

Calculations:

Calculations are provided here to confirm reported data. Rates of reduction are expressed as the difference between Pre-construction (Pre) and Post-construction (Post) flows as a percentage of Pre-construction flows.

Flow rate comparison
As reported by Duke FMD civil engineers, the pond reduces the overall outflow volume of 1-year, 2-year, and 10-year storms by 225.82 cubic feet per second (cfs) or 64% compared to pre-storm estimates; 373.55 cfs or 54%; and **719.44 cfs** or **40%** respectively. Calculations below confirm these rates based on pre- and post-construction outflows.

1-year storm outflow
Pre-construction outflow (cfs) = 352.89
Post-construction outflow (cfs) = 127.07
Rate of reduction (%) = (Pre - Post) / Pre
= 225.82 cfs / 352.89 cfs
= 0.6399 = 64%

2-year storm
Pre-construction outflow (cfs) = 691.76
Post-construction outflow (cfs) = 318.21
Rate of reduction (%) = (Pre - Post) / Pre
= 373.55 cfs / 691.76 cfs
= 0.54 = 54%

10-year storm
Pre-construction outflow (cfs) = 1,798.6

Post-construction outflow (cfs) = 1,079.16
Rate of reduction (%) = 719.44 cfs / 1,798.6 cfs
= 0.40 = **40%**

Sources:
Ryan Lavinder, Civil Engineer at Duke Utility & Engineering Services Facilities Management Department, email to Auburn University research team, March 2020.

US EPA National Stormwater Calculator. 2020. "National Stormwater Calculator Report." Durham.

Limitations:
Data were provided by Duke FMD and not independently verified by the research team. The research team was not able to conduct outflow rate sampling on-site during the CSI schedule due to pandemic-related travel restrictions and so relied on provided historic design and monitoring data.

Habitat Quality

- ***Increases ecological quality by an increase in Floristic Quality Index (FQI) from 18 to 45.9. An FQI above 35 is considered to be a "natural area" in terms of ecological value.***

Background:
Site demolition included removal of 1,596 trees to clear the area required for pond construction. At the edges of the demolition limits, the team worked to preserve as much of the existing pine-dominant forest as feasible. Approximately 52% of all plants installed for the project are plants native to Durham County, including 67% of trees and shrubs and 88% of whips. Overall, nearly 98% of species installed or transplanted are native to the southeast US. Established vegetation stabilizes soils and use of native species promotes resilient habitats.

Method:
The research team used the web-based Universal Floristic Quality Assessment Index tool to evaluate FQA/I values for pre-construction and installed tree stands.

A full survey of pre-construction vegetation was not available to the research team, or previously to the design team, but Duke Forest did complete a tree survey prior to project demolition so the research team evaluated changes in ecological quality based only on tree diversity. The team compared the tree survey list to the plant list provided on permit drawings by N. The team assumed tree species would be a sufficient proxy for ecological quality, considering the dominance of the pre-construction forest and also the number of trees installed for the project.

The FQI is an indication of native vegetative quality for an area. Scores of 1-19 indicate low vegetative quality; scores 20-35 indicate high vegetative quality; and scores above 35 indicate "natural area" quality. Wetlands with a FQI of 20 or greater are considered high quality aquatic resources (US FWS, Midwest Region Endangered Species, 2020).

Floristic Quality Assessment (FQA) is based on coefficients of "conservatism" assigned to individual plant species (0-to-10 scale, with non-natives assigned a 0 score) based on their tolerance to degradation and the degree to which the species is faithful to natural remnant habitats (Swink & Wilhelm 1994).

Highly conservative species (C>7) are associated with each other under long-unchanged conditions similar to those under which the ecological communities evolved. Least conservative species (C<3) are adapted to extreme anthropogenic or natural degradation. FQI is calculated as a weighted average of C by species richness: $I = C\sqrt{n}$

The project also scores 17.85 on the Plant Stewardship Index, which depends primarily on a simple count of distinct species. The research team has not reported this score as a specific benefit since a simple species count is less informative than FQA/I in that it does not value species or plant community quality.

<u>Calculations</u>:

<u>FQA Post-construction (All plants)</u>

FQA DB Region:	Piedmont region of the Southeast (NC, SC, GA, AL, MS, FL, TN, KY)		
Publication Year:	2013		
Conservatism-Based Metrics			
Total Mean C:	45.9		
Species Richness:			
Total FQI:	45.9		
Native FQI:	47		
Total Species:	75		
Native Species:	73	97.30%	

Non-native Species:	2	2.70%	

FQA Pre-construction (Trees only)

FQA DB Region:	Piedmont region of the Southeast (NC, SC, GA, AL, MS, FL, TN, KY)		
Publication Year:	2013		
Conservatism-Based Metrics			
Total Mean C:	6		
Species Richness:			
Total FQI:	18		
Native FQI:	18		
Total Species:	9		
Native Species:	9	100%	
Non-native Species:	-	0%	

Table 02. FQA calculations.

Sources:

Curtis Richardson, PhD, Director; Neal Flanagan, PhD; and Mengchi Ho, PhD. 2019. Duke Pond Water Quality and Nutrient Budget Progress Report, Fourth Annual Report (2018 Monitoring). Durham: Duke University Wetland Center.

Giuliano, B. (2016). Effects of Drawdown on water quality and temperature in Duke University's chiller pond. Durham: Duke University.

Level III and IV Ecoregions by State. United States Environmental Protection Agency. Accessed at https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-state

Mid-Atlantic Wetlands Workgroup. Floristic Quality Assessment Index (FQAI). Accessed at http://www.mawwg.psu.edu/tools/detail/floristic-quality-assessment-index-fqai

Nelson Byrd Woltz Landscape Architects. 2013. Duke Water Reclamation Pond: Final Construction Documents. Durham, North Carolina.

Universal FQA. 2020. "Duke Reclamation Pond." Inventory Assessment. Accessed at https://universalfqa.org/

US Fish and Wildlife Service. Midwest Region Endangered Species. 2020. "Floristic Quality Assessment." Bloomington, Minnesota, May. https://www.fws.gov/midwest/endangered/section7/s7process/plants/FQA.html#:~:text=The%20FQI%20is%20an%20indication,considered%20high%20quality%20aquatic%20resources.

<u>Limitations</u>:
FQA/I analysis was completed based on pre-construction tree inventory and design drawings provided by NBW. The current and complete on-site plant matrix was not determined by the research team due to fieldwork restrictions. FQA/I database is somewhat outdated, using published data from 2013. About 35% of installed tree species (34.9% or 52 of all 149 specified; and 7 of 20 tree species) did not appear in the FQA/I data and so were left out of the diversity count. Therefore, the FQA/I calculation may be somewhat suppressed -- missing species are classified as southeast natives -- but this is not a significant impact as the score is still above the minimum for “natural area,” which is presumed by the index to have the highest perceived ecological value.

Notably, the two species indicated as “non-native” by the FQA/I database -- Magnolia grandiflora (Southern Magnolia) and Taxondium distichum (Bald cypress) -- are generally considered native to North Carolina, but in Durham County fall just outside of the documented “native” range according to the USDA. Both species are prevalent at the Duke University campus, so this qualification points to another limit of the FQA/I index, which does not draw from a state-specific dataset for North Carolina.

FQA/I inputs are based on permit drawings rather than installed material. Interviews with NBW staff confirmed that availability of specified plant material was confirmed to the greatest extent possible during design to ensure few substitutions were required during construction. Therefore, the difference in FQI calculations is assumed to be minimal. If a species was not present in the FQI database, it was excluded from the calculation.

On-site observations and vegetation surveys recorded in Monitoring Reports by the Duke Wetland Center revealed that plant species, quantity, individual distributions, and locations have shifted relative to the NBW landscape construction drawings. These shifts are generally due to succession at the meadow and wetland planting areas, maintenance practices, and appearance and propagation of introduced volunteer herbaceous species. Tree mortality has been negligible. Such changes are unlikely to significantly impact FQA/I estimates, given that planting areas are categorized quite coarsely, and some quantities of proposed installed plants only use area counts.

Populations & Species Richness

- ***Provides habitat for at least 47 species of birds observed on-site. Of these, 23 species were observed to nest on site and 24 use it as a migratory stop-over point.***

Background:
Duke Pond is listed as a birding hotspot on eBird.org, an online database of bird distribution and abundance based on real-time observations, managed by the Cornell Lab of Ornithology. It can be used to measure bird migration and habitat quality for bird species. Hotspots are public birding locations created by eBird users, or simply a set of locations visited by multiple users over time - but not necessarily outstanding locations for birds or birding.

Method:
The improvement of habitat was a primary ecological goal for the project. The team chose to focus on bird habitat as a readily available metric for evaluating improvement based on public data from citizen scientist bird-watching databases. Habitat, including food, water, and shelter, is a critical and integral part of a bird's identity, as it includes compositions and structures of fauna with which the species can adapt or evolve. The research team consulted eBird.org to quantify the bird species observed on site. See Appendix B for a full list of birds reported by eBird users as being seen at Duke Pond. Species most commonly observed at the pond landscapes include the White-throated Sparrow, European Starling, Common Grackle, Cedar Waxwing, Cliff Swallow, and Mallard (eBird, 2020), as well as the Belted Kingfisher, Great Blue Heron, Eastern Bluebird, Hooded Merganser, and Song sparrow (Duke Wetland Center, 2019).

Calculations:

Bird count observation change (identified at eBird.org)

Year	Unique species	Total species	Number of birds
2015	1	1	1
2016	3	4	9
2017	4	8	18
2018	6	14	7

2019	33	47	70
2020	47	94	80
Totals	87 species (**47 unique**)		176 total birds across all species and years

Table 03. Bird counts.

Sources:

eBird. 2015-2020. eBird [web application], Cornell Lab of Ornithology, Ithaca, New York. Available: http://www.ebird.org. Accessed at https://ebird.org/hotspot/L4754196?yr=last10&m=.

Duke University Wetland Center. 2019. "A Checklist of the Birds of Duke Pond." Duke University Wetland Center, Duke University, Durham. https://sites.nicholas.duke.edu/wetland/files/2020/05/pondbirds.pdf.

Limitations:

Observation data were not independently verified by the research team. This report relies on observation data by citizen scientists as recorded in the eBird web-based application. As such, this is not a rigorous or specific time-based study, nor is it concerned with identifying particular use by a given species (for example, nesting, or migration stop-over) or abundance of that species. Differences in observation counts may not be directly attributed to pond construction, especially considering that the use of eBird has increased dramatically in recent years, resulting in significantly more recorded observations. Observation of particular migrating, breeding, or nesting species only notes an incidental moment and does not guarantee the study site provides a consistent or on-going habitat benefit. Nor do observations suggest a particularly repeatable sampling method; species abundance cannot be correlated to particular physical areas of the project reporting site. Standard sampling methods for assessing bird species abundance are point counts, line transects, spot-mapping, or variable distance methods, along with established and consistent time-frames for counts.

Reused & Recycled Materials

- ***Reused 38,000 linear ft of site-harvested lumber in the project, saving the university nearly $20,000. The university also stored approximately 212,800 linear ft of unused harvested lumber, valued at nearly $130,000, for future construction projects.***

Background:
Duke's history of environmental conservation and stewardship dates to the 1931 establishment of Duke Forest, 7,000 acres of forest and field managed for education and research. With the tree clearing required at the Pond site, the University has been able to produce enough raw timber to not only build all the wood structures at the Pond (overlook, bridge, wetland boardwalk, pavilion and pond overlook, pumphouse cladding) but also to store a surplus of pine for use in other building projects on campus. Waste from wood processing was used as mulch at the Pond and elsewhere on campus for planting beds and trails.

Duke Forest provided several informal inventories of wood harvest. Wood value was estimated by Duke Forest prior to timber harvest based on a pre-construction tree inventory, and lumber costs were estimated by LeChase Construction during construction cost estimating. The client and design team did not consider alternative lumber sources and so lumber cost estimates were not completed during project construction cost estimating phases.

Method:
The research team compared timber value estimates by Duke Forest to lumber cost data sourced during the case study project to evaluate estimated unit and total market values for the harvested timber and processed lumber. On a unit-cost basis, the project was more expensive per board foot of lumber than purchasing lumber from regional suppliers. By processing timber harvested from site, Duke Forest added the value of a lumber stockpile, which reduced material waste on the project and will reduce new material and energy consumption on future projects.

Calculations:

Abbreviations
BF = board feet
MBF = 1,000 board feet
LF = linear feet

Material volume and value inventory for timber and lumber harvested on-site

	BF harvested	BF used	LF harvested	
Pine sawtimber	190,440	23,532	36,216	
Hardwood sawtimber	47,120	1,247	1,808	
Total unused lumber	212,781.00		**38,024.00**	

190 MBF pine wood processed	$ 37,326.99		Savings pine	$ 31,866.21
47.12 MBF Hardwood sawtimber value	$ 8,535.45		Saving oak	$ 59,788.55

Table 2. Material value inventory for timber harvest and lumber supply (Tree Inventory and Timber Utilization estimates from Duke Forest, and material takeoffs from LeChase construction contractor).

Market BF prices	**Toney Lumber**	**Lowe's**	**Home Depot**
a. Unit cost (Pine cost per foot)	$ 0.39	$ 0.33	$ 0.37
Average pine market unit price (Σ Unit cost/3)	$ 0.36		
b. Pine sawtimber (BF used in site)	23,532	23,532	23,532
Cost material (a*b)	$ 8,549.96	$ 7,765.56	$ 8,706.84
c. Average total market pine value (Σ Cost material/3)	$ 8,340.79		
d. Pine sawtimber (BF harvested)	190,440		
190 MBF pine wood processed market value (c*d)	$ 69,193.20		
e. Unit cost (Oak cost per foot)	$ ------	$ 1.45	$ 1.45
Average oak market unit price (Σ Unit cost/3)	$ 1.45		
f. Hardwood sawtimber (BF used in site)	1,247	1,247	1,247

Cost material (e*f)	$ 1,808.15	$ 1,808.15	$ 1,808.15
g. Average total market oak value (Σ Cost material/3)	$ 1,808.15		
h. Hardwood sawtimber (BF harvested)			
47.12 MBF Hardwood sawtimber value (g*h)	$ 68,324.00		

Table 02. Material and market value inventory for timber harvest and lumber supply (Research team calculations based on pre- and post-construction data from Duke Forest and LeChase Construction).

<u>Total stored lumber</u>
(provided by Duke Forest, Timber Utilization Summary, December 2013; and LeChase construction, Preliminary Lumber Quantity Survey, May 2013)

Total harvested timber (Mbf) = Pine harvested (bf) + Hardwood harvested (bf)
= 190,440 bf + 47,120 bf
= 237,560 bf
= 237.56 Mbf

Total used lumber (Mbf) = Pine used (bf) + Hardwood used (bf)
= 23,532 bf + 1,247 bf
= 24,779 bf
= 24.8 Mbf

Stored lumber (Mbf) = Harvested timber (bf) - Used lumber (bf)
= 237.6 Mbf - 24.8 Mbf
= **212.8 Mbf**

Total used lumber (LF) = Pine used (LF) + Hardwood used (LF)
= 36,216 LF + 1,808 LF
= 38,024 LF

<u>Total value of on-site timber harvest to Duke Forest</u>
(provided by Duke Forest, Timber Utilization Summary, December 2013)

Value of harvested timber

Market value, pine sawtimber ($) = $37,326.99
Market value, hardwood sawtimber ($) = $ 8,535.45
Market value, pine pulpwood ($) = $ 2,043.08

Market value, hardwood sawtimber ($) = $ 838.10
Total value ($) = $48,743.62

Costs of timber processing

Logging = $ 4,157.00
(including transport to sawmill)
Sawmilling, stacking, drying = $11,316.26
(including transport to treatment plant and Duke)
Pressure treating = $ 6,069.68
Total value of processing = $28,258.94

Other credit values, including transportation = $ 2,045.00

Total value to Duke Forest ($) = Harvest value ($) - Processing costs ($)
= $48,743.62 - (28,258.94 +$2,045.00)
= **$18,439.68**

<u>Market value of timber harvested</u>
Average unit cost, harvested pine ($) = Sum of pine unit costs ($/bf) / Count of pine unit costs
= ($0.39 + $0.33 + $0.37)/3
= $1.09 / 3
= $0.36/bf

Average unit cost, hardwood ($) = Sum of oak unit costs ($/bf) / Count of oak unit costs
= ($1.45 + $1.45)/2
= $2.90 / 2
= $1.45/bf

Total market value, harvested timber ($) = Market value, pine ($) + Market value, hardwood ($)
= $69,193.20 + $68,324.00
= $137,517.20

<u>Cost comparison of lumber used</u>
Market cost (2020), pine used ($) = Unit cost, pine ($/bf) * Pine used(bf)
= $0.36/bf * 23,532 bf
= $8,340.79

Market cost (2020), hardwood ($) = Unit cost, hardwood ($/bf) * Hardwood harvested (bf)
= $1.45/bf * 1,247 bf
= $1,808.15

Total cost of lumber used on site ($) = Cost of pine used ($) - Cost of hardwoods used ($)
= $8,340.79 + $1,808.15
= $10,148.94

Market value of unused lumber

Residual value to Duke Forest ($) = Value, harvested timber ($) - Cost, processed lumber ($)
= $137,517.20 - $10,148.94
= **$127,368.26**

Sources:

Stephen Carrow, Civil Engineer at Duke Utility & Engineering Services Facilities Management Department, provided in email with the Auburn University research team, March 2020.

James Caldwell, PE, Civil Engineer at McAdams, Inc, provided in email with the Auburn University research team, March 2020.

Schramm, S. (30 July 2018) Following the Flow of Water. Retrieved from Duke Today: https://today.duke.edu/2018/07/following-flow-water

Schramm, S. (18 June 2018). Duke Stone: From Quarry to Campus. Retrieved from Duke Today: https://today.duke.edu/2018/06/duke-stone-quarry-campus

Timber Utilization Summary. (2 December 2013). Duke Forest.

Wood Quantities Usable. (23 August 2012). Duke University Facilities Management Department.

Wood Use Plan. (2013). Duke University Facilities Management Department.

Pond Tree Count. (20 November 2012). Duke Forest and Duke University Facilities Management Department.

Preliminary Lumber Quantity Survey. LeChase Construction. 8 May 2013.

Lowe's. 2020. *Building supplies.* Durham. https://www.lowes.com/.

Home Depot. 2020. *Lumber and Composites.* Durham. https://www.homedepot.com/b/Lumber-Composites/N-5yc1vZbqpg.

Toney Lumber. Lumber prices. Provided in a phone interview with the Auburn University research team, May 2020.

Limitations:

For purposes of this comparison and material value calculation, the research team assumes all unused lumber was stored for reuse; some was sold and some has since been used, though a specific inventory of these values was not available.

- ***Reduced estimated transportation impacts by about 4.7 metric tons of carbon dioxide by processing timber less than 50 miles from the site as compared to procuring lumber from more distant regional suppliers (such as within 500 miles as required by LEED rating systems or 200 miles commonly practiced by southeast suppliers). This is the carbon equivalent of a single passenger vehicle driving 10,000 miles.***

Background:
The Pond represents the continuation of an investment by Duke University into the material supply chain for construction on campus. The University was established at its particular location in part because of its proximity to a stone quarry. Duke Stone is a unique sedimentary stone endemic to North Carolina's so-called "slate belt" in the Appalachian range that clads many West Campus buildings. The stone is used on retaining walls at the Pond's Circuit Drive entrance, linking the project to both the underlying geology and architectural aesthetic of the campus.

The extensive amount of forest clearing required to establish sufficient pond area also presented an opportunity to generate usable material for building various structures, and so to offset some energy and economic costs for the project.

Duke Forest managed the harvest, including a complete inventory of the existing forest canopy and timber processing by two local saw-mills, Nikitin (Cates) Mill and Braxton Mill. Removed trees were not specifically evaluated for health or ecological contribution.

Commercial warehouses in North America typically source lumber from mills in the Pacific Northwest. Pressure treated lumber comes from different vendors depending on region. CM Tucker Lumber Companies, based in South Carolina, distributes processed lumber to several home building supply stores in Durham NC. Their treatment plant in Hendersonville, NC, about 240 miles west of Durham, sources over 95% of their treated pine and oak from forests in North Carolina, South Carolina, Georgia and Virginia (List, 2020). Less commonly, suppliers source large pine timbers from Mississippi or Louisiana, and more typically within 200 miles of a given mill or treatment plant.

Lumber prices were steady from 2014 to 2017 and increased sharply in 2018 to a historic all-time global high of US$659/MBF in May 2018. As of June 2020, lumber prices are higher (US$428.10/MBF) than at the same time in 2014 (US$337.50/1MBF). Historically, lumber reached an all time global high of 659 US$/1,000BF in May 2018 (Lumber 1978-2020 Data, Trading Economics).

Method:
Tree harvest data were provided by Duke Forest and not independently verified by the research team. Proposed tree species and totals were provided in planting plans by NBW.

Calculations:

Lumber quantities from above Benefit.

Carbon impact comparison conversion
Transportation impacts
Dry weight of van (short tons) = 24 tons

Weights of wood species
1 kg/in = 2.205 lbs/in
1 lb/in = 0.0005 tons/in
Weight, pine (tons/in) = 0.4kg/in= 0.000440925 tons/in
Weight, oak (tons/in) = 2.2kg/in= 0.002436108 tons/in

Total length of wood (inches)
(*LeChase construction, Preliminary Lumber Quantity Survey, May 2013*)
Rough sawn, untreated pine and Decking (Nominal dimension and LF quantity)

1x4	2,603
1x6	1,735
1x8	2,567
2x4	18,810
2x6	211
12	3,312
18	3,114
20	600
10	960
8	2,304
Total	36,216

Rough sawn white oak and oak (Nominal dimension and LF quantity)
1.5 * 7.25 * 16 = 944
0.75 * 7.25 * 16 = 864

Total 1,808

Total wood, length (pine) = 36,216 inches
Total wood, length (oak) = 1,808 inches

Total wood weight = Pine weight * amount in inches + Oak weight*amount in inches
= (0.000440925 s. tons/inches*36,216 inches) + (0.002436108 s. tons/inches*1,808 inches)
= 15.97 s. tons + 4.40 s. tons
= 20.37 short tons

Total weight = Dry van weight + Total wood weight
= 24 short tons + 20.37 short tons
= 44.37 short tons

Distance traveled
Duke University to Braxton Mill = 29.7 miles (59.4 miles round trip)
Duke University to Nikitin (Cates) Mill = 14.35 miles (28.70 miles round trip)

Average distance to regional lumber suppliers (Hendersonville NC) = 96.26 miles

Greenhouse Gas Emissions = D*W*EF
Provided from EDF Green Freight Handbook
D = Distance traveled (miles)
W = Total weight of loaded truck (tons)
EF = Emissions factor
1,000,000 grams = metric ton

Emission factor (EF) for a flatbed truck (grams/mile) = 1,800 g/mi

Emissions = D * W * EF
= (Distance to mill * Total weight * Emission Factor for a dry van) / 1,000,000 grams
= (59.4 miles * 44.37 short tons * 1,800 g/mi) / 1,000,000 g
= 4,744,040.4 g / 1,000,000 g
= **4.744 metric tons of CO_2**

Sources:

Lumber 1978-2020 Data (June 2020). Accessed at: tradingeconomics.com/commodity/lumber

Duke Forest. (2014). Tree Harvest Estimate.

Judd Edeburn (former Duke Forest Director) and Sara Childs (Duke Forest Director), interview with the Auburn University research team, 22 May 2020.

Wood Quantities Usable. (23 August 2012). Duke University Facilities Management Department.

Stephen Carrow, Civil Engineer at Duke Utility & Engineering Services Facilities Management Department, provided in email with the Auburn University research team, March 2020.

James Caldwell, PE, Civil Engineer at McAdams, Inc, provided in email with the Auburn University research team, March 2020.

Mathers, Jason. 2015. "Green Freight Math: How to Calculate Emissions for a Truck Move." EDF Green Freight Handbook. EDF+Business, March 24. Accessed at business.edf.org/insights/green-freight-math-how-to-calculate-emissions-for-a-truck-move/

Jason Mathers, Elena Craft, Ph.D., Marcelo Norsworthy, Christina Wolfe. *The Green Freight Handbook.* Environmental Defense Fund, 2015. Accessed at storage.googleapis.com/scsc/Green%20Freight/EDF-Green-Freight-Handbook.pdf.

Environmental Protection Agency. *Greenhouse Gas Emissions from a Typical Passenger Vehicle.* United States Environmental Protection Agency, 2018. Accessed at epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle#:~:text=typical%20passenger%20vehicle%3F-,A%20typical%20passenger%20vehicle%20emits%20about%204.6%20metric%20tons%20of,8%2C887%20grams%20of%20CO2

Limitations:
Lumber market cost estimates in this case study use 2020 instead of 2014 prices. So, the financial advantage of on-site sourcing and local processing would have been slightly less than indicated above. The design and construction teams did not compare or estimate lumber costs during construction cost estimating.

- ***Converted 665 tons of timber pulpwood into approximately 30,230 cf of mulch, equivalent to 15,110 standard bags of mulch.***

Background:
Significant quantities of waste wood are generated by timber processing. Much of this waste is reclaimed into paper products and in some cases can be converted into mulch.

Inferior trees and components are typically harvested for production of pulpwood, which usually derives from four types of woody materials in a mixed logging operation: a) open-grown, low- and heavily branched trees that are poor sawlogs; b) dead or diseased trees; c) tops cut from trees harvested for sawlogs; and d) trees too small to harvest for sawlogs.

Method:
At the pond, as much waste wood as possible was used to produce mulch for use on trails as an alternative surface to crushed stone, more suitable for the woodland edges of the hillsides, and also mulch for planting beds, where it controls temperature and moisture, and helps limit weed growth.

LeChase Construction and Duke Forest managed the timber harvest and processing and so provided data on harvest quantities.

Calculations:

Mulch bag comparison conversion
Typical size of commercially available mulch bag = 2 cubic feet (cf)
Mulch bag (lbs) = Mulch bag (cf) * (44 lbs/1 cf)

= 2 cf * (44 lbs/1 cf)
= 88 lbs

1 ton = 2,000 lbs
Mulch volume (cf) = 665 tons pulpwood * (2,000 lbs / 1 ton) * (1 cf mulch / 44 lbs)
= 30,227,27 cf

Mulch (bags) = (1 bag / 2 cf) * 30,227.27 cf
= 15,113.64 bags

<u>Sources</u>:
Duke Forest. (2014). Tree Harvest Estimate.

Judd Edeburn (former Duke Forest Director) and Sara Childs (Duke Forest Director), interview with the Auburn University research team, 22 May 2020.

<u>Limitations</u>:
For the purposes of this comparison and in the absence of records quantifying otherwise, the research team assumed all pulpwood was converted to mulch. There was not likely 100% conversion through the full processing cycle.

Social Benefits

Recreational & Social Value

- ***Creates places for informal gathering for the campus community, with 80% of 52 surveyed campus community members reporting using the site for recreational activities. 12% reported seeking out the pond for relaxation, and nearly 60% visit 2-3 times per month.***

Educational Value

- ***Serves as a learning laboratory for the Nichols School for the Environment, with 12% of 52 surveyed campus community members reporting that they have attended a class or an event at the pond.***

Scenic Value

- ***Increased perceptions of campus aesthetic value and experience according to 96% of 52 surveyed campus community members.***

<u>Background</u>:
Since 2013, Mark Hough, Duke University Landscape Architect, has worked with faculty, staff, and students through the Duke University Nicholas School of the Environment and staff and students through Sustainable Duke to help bring awareness to possible educational and other opportunities at the stormwater reclamation pond. That year, before pond construction, a survey

by students Scott Valentine, Bonnie Delaune, Michael McCammond, and Jennifer Walker found that over 80% of campus community members respondents (over 400 undergraduate students) anticipated using the walking trails at the Pond and visiting primarily for relaxation (85%) and to enjoy the landscape (81%). Nearly 60% of respondents anticipated visiting the Pond 1-3 times per month (58%)

The same study found that nearly 20% of respondents anticipated participating in research centered at the Pond (17%) or to directly conduct research there but also found that 73% of respondents (over 400 undergraduate students) had not heard about Duke Pond.

A 2017 survey conducted by Allie Charlton, Libby Dotson, Dhara Patel, and Joe Lee, who were students in the “Campus as Lab” course (ENVIRON 245), reported that 92% (of 131 students) were unaware of the stormwater management role the Pond plays for the campus. In that survey, however, more than 103 students (of 131 total respondents) reported interest in using the site each year for classes or educational events. 69% of visitors anticipated attending a class or education event at the site (Campus as Lab, 2017).

From that 2017 survey, 82% of students (107 of 131 respondents) see Duke’s physical campus as a resource for their education.

<u>Method</u>:
The CSI research team created a survey for students, staff, faculty, and community members at Duke University. The web-based survey was distributed via Sustainable Duke, the branch of the Office of Sustainability charged with reducing the environmental impact of Duke University, strategic planning for sustainability, educating the campus community regarding sustainability on campus, and developing programs to positively influence campus sustainability behavior and operations.

The survey period was from September 2020 to January 2021, and it was distributed to approximately 1,500 subscribers of Sustainable Duke’s e-mail newsletter, who are typically students, staff, faculty, and community members at Duke University. 53 total survey responses were received, a 3.5% response rate. Survey data was compiled with the Qualtrics platform, which was also used to distribute the survey. See the Appendix for survey questions.

To assess Recreational & Social Value, the research team included questions that matched the wording of the 2013 survey in order to communicate consistent results for comparison about Pond visitation frequency and motivations. The 60% of 2020 respondents that reported visiting the Pond 2-3 times per month is consistent with the 2013 survey prior to the Pond’s construction, meaning that campus users visit about as often in general as the initial survey predicted.

<u>Calculations</u>:
In the 2020 survey, 9% of respondents reported primarily visiting the Pond for classes or educational activities (8.77%). Of those respondents, 60% visit for class, and 20% each for educational events or programming (not classes) or field research.

In the 2020 survey, 92% of students (92.3% or 22 of the 24 students among the 53 total campus community member respondents).

Sources:

Duke University. 2017. "Fall 2017 Campus As Lab: Survey Analysis." Durham, North Carolina.

Charlton, A., Dotson, L., Patel, D., Lee, J. 2016. "Campus as Lab." Durham, North Carolina.

Valentine, S., Delaune, B., McCammond, M., Walker, J. 2013. "How can we balance ecosystem, education, recreational, and utility aspects of the Duke Water Reclamation Pond?" Durham, North Carolina.

Loaiza, L. and Hogge, T. 2021. "Pond Use Survey: LAF 2020 CSI Duke Water Reclamation Pond." September 2020 - February 2021.

Limitations:

Pandemic-related restrictions eliminated possibilities for on-site solicitation, respondent recruitment, and observation.

The 53 total survey responses and 3.5% response rate are well below expectations -- and below the 40% response rate of the 2013 survey -- but conveys a reasonable confidence interval, or margin-of-error, of 13.25.

Cost Comparison

- ***Construction of Duke Pond cost approximately $11.5 million. This cost, although 28% higher than the estimated $9 million initial budget for a conventional stormwater retention pond, enhanced ecological and cultural value by creating a high-performance landscape and hydrological park accessible to the university community and the broader public. Projections suggest that savings for water costs alone will cover the cost of the project by 2025.***

Background:

The pond as originally conceived would have served a much more limited role as simply a component of the campus water management infrastructure, whereas the realized project serves social, educational, and ecological goals beyond the utility function alone. Preliminary project budgets proposed a cost of $9 million for engineering design and construction of a storage pond to hold sufficient water to supply the adjacent Chiller Plant #2 with 20% of its projected annual demand. Such a pond was projected to also help mitigate flood events in the Sandy Creek watershed and contribute to water quality improvements in the Cape Fear River watershed.

Method:
Costs were obtained from project documentation and published accounts of total costs. Simple percentage calculations show the cost difference. The broader case study makes a case for the ecological and cultural values (and associated economic benefits), though these are more complex to quantify.

See the above Water Conservation Benefit for analysis of water savings.

Calculations:
Preliminary estimated engineered-only project cost = $9 million
Final estimated landscape design and construction cost = $11.5 million

Percentage change of project cost = Final cost / Preliminary cost * 100
= ($11,500,000 / $9,000,000) * 100
= 127.8%

Sources:
Mark Hough, Duke University Landscape Architect, provided in email to the Auburn University research team, February 2020.

Limitations:
Calculations are based on a published total project cost of $11.5 million. Actual total project costs for all design and construction were higher, perhaps closer to $13 million (email conversation with Mark Hough, 2020). However, our estimates and university data suggest that even at this increased cost, water savings alone will pay-off even these increased project costs by 2025. (See Projected Payoff calculations at Water Conservation benefits.)

Appendix A

Plants

The following represents a complete inventory of plants specified and installed at Duke Water Reclamation Pond. The Wetland Center continues to work with Duke University Facilities Management Department on the selection, maintenance, and monitoring of native wetland vegetation appropriate to the site.

Quantity	Scientific Name	Common Name	C Value
499	**TREES**		
3	Acer Floridanum	Southern Sugar Maple	-
12	Acer rubrum 'October Glory'	October Glory' Red Maple	3
46	Amerlanchier x grandifolia 'Autumn Brilliance'	Autumn Brilliance Serviceberry	-
39	Asimina triloba	Pawpaw	7
31	Betula nigra 'Heritage'	Heritage' River Birch	4
3	Carpinus caroliniana	Musclewood	5
2	Celtis laevigata	Netleaf Hackberry	4
73	Cercis canadensis	Redbud	-
45	Chamaecyparis thyoides	Atlantic White Cedar	0
3	Chioanthus virginicus	Fringe Tree	6
2	Crataegus phaenopyrum 'Princeton Sentry'	Princeton Sentry' Washington Hawthorne	5
16	Cyrilla racemiflora	Swamp Titi	7
11	Diospyros virginiana	Persimmon	4
19	Ilex decidua	Possumhaw	6
22	Ilex opaca	American Holly	5
2	Juglans nigra	Black Walnut	-
10	Juniperus virginiana	Eastern Red Cedar	-
3	Liquidambar styraciflua	Sweet Gum	3
19	Liriodendron tulipifera	Tulip Poplar	-
6	Magnolia grandiflora	Southern Magnolia	-

8	Magnolia virginiana	Sweetbay Magnolia	7
16	Nyssa sylvatica 'Red Rage'	Red Rage' Black Gum	6
6	Ostrya virginiana	Hop hornbeam	-
2	Oxydendrum arboreum	Sourwood	-
5	Pinus palustris	Longleaf Pine	8
33	Pinus strobus	White Pine	3
14	Platanus occidentalis	American Sycamore	5
2	Populus deltoides	Eastern Cottonwood	5
3	Quercus laurifolia	Laurel Oak	6
7	Quercus lyrata	Overcup Oak	7
4	Quercus nigra	Water Oak	3
5	Quercus pagoda	Cherrybark Oak	7
2	Quercus phellos	Willow Oak	5
7	Quercus rubra	Red Oak	-
5	Quercus shumardii	Shumard Oak	7
13	Taxodium distichum	Bald Cypress	-

Quantity/ acre	Scientific Name	Common Name	C
580 per ac density	**WHIPS**		
0.15	Liriodendron Tulipifera	Tulip Poplar	-
0.10	Prunus serotina	Black Cherry	-
0.20	Pinus strobus	White Pine	-
0.05	Ilex opaca	American Holly	5
0.10	Juglans nigra	Black Walnut	-
0.20	Juniperus virginiana	Eastern Red Cedar	-
0.20	Quercus rubra	Red Oak	-

Quantity/Area	Scientific Name	Common Name	C
1,258	**SHRUBS**		
9	Alnus serrulata	Smooth Alder	5
118	Cephalanthus occidentalis	Buttonbush	5
55	Clethra alnifolia ' Hummingbird'	Hummingbird Summersweet	7
25	Clethra alnifolia ' Compacta'	Compact Summersweet	-
93	Cornus amomum	Silky dogwood	5
162	Fothergilla gardenii 'Mt. Airy'	Mt. Airy Fothergilla	-
157	Ilex glabra	Inkberry Holly	6
101	Ilex verticillata 'Winter Red'	Winterberry Holly ' Winter Red'	7
8	Ilex vomitoria	Yaupon	-
86	Itea virginica 'Henry's Garnet'	Virginia Sweetspire 'Henry's Garnet'	7
14	Lindera benzoin	Spicebush	6
44	Morella cerifera (Myrica cerifera) 'Luray'	Southern Wax Myrtle 'Luray'	5
15	Photinia pyrifolia 'Brilliantisima'	Red Chokeberry 'Brilliantissima'	7
15	Rhododendron nudiflorum	Northern rose azalea	6
15	Rhododendron periclymenoides	Pinxsterbloom azalea	6
73	Rhus copallina	Flameleaf sumac	-
81	Rhus glabra	Smooth sumac	-
107	Rosa palustris	Swamp rose	6
11	Vaccinium fuscatum	Black highbush blueberry	7
35	Viburnum acerifolium	Mapleleaf Viburnum	-

34	Viburnum dentatum	Arrowood viburnum	6

Quantity/Area	Scientific Name	Common Name	C
25,725	**HERBACEOUS**		
205	Baptisia australis	False indigo	-
770	Chasmanthium latifolium	River Oats	6
940	Coreopsis lanceolata	Tickseed	-
535	Cyperus erythrorhizos	Red rooted sedge	4
250	Doellingeria umbellata	Flat-top white aster	7
3,791	Eleocharis palustris	Spikerush	-
390	Eupatorium purpureum	Joe Pye Weed	6
280	Gentiana clausa	Bottle gentian	-
605	Helianthus angustifolius	Swamp sunflower	5
315	Hibiscus moscheutos	Crimsoneyed rosemallow	5
145	Hydrocotyle umbellata	Manyflower marshpennywort	4
195	Iris cristata	Dwarf crested iris	-
415	Iris virginica	Virginia Blue Flag	7
950	Justicia americana	American water-willow	6
1,040	Juncus effusus	Common rush	-
1,210	Leersia oryzoides	Rice Cutgrass	4
890	Lobelia cardinalis	Cardinal Flower	5
625	Luziola fluitans	Southern watergrass	-
660	Lysimachia terrestris	Swamp candle	-
315	Nelumbo lutea	American lotus	-
1,495	Nuphar lutea	Yellow Pond Lily	5
850	Nymphaea odorata	Water lily	4
220	Orontium aquaticum	Golden club	7

1,625	Osmunda cinnamomea	Cinnamon Fern	-
270	Osmunda regalis	Royal fern	7
1,415	Pontederia cordata	Pickerelweed	5
520	Rhynchospora colorata	star sedge	-
290	Rudbeckia fulgida	Rudbeckia	4
435	Rudbeckia laciniata 'Herbstonne'	Cutleaf coneflower	5
605	Sagittaria sp.	Lanceleaf Arrowhead	6
160	Saururus cernuus	Lizard's tail	6
227	Schoenoplectus pungens	Common threesquare (sedge)	-
375	Scutellaria integrifolia	Hyssop skullcap	5
830	Solidago rugosa 'Fireworks'	Goldenrod	3
392	Sorghastrum nutans	Indiangrass	-
280	Stokesia laevis	Stoke's aster	-
845	Vernonia novaboracensis	Ironweed	-
365	Veronicastrum virginicum	Culvers root	8

Quantity/Area	Scientific Name	Common Name	C
7 lbs / ac	**PERENNIALS**		
1	Asclepias syriaca	Common Milkweed	-
1.5	Ascelpias tuberosa	Butterfly Milkweed	-
0.50	Aster lateriflorus	Heath Aster	-
1	Coreopsis tinctoria	Golden Tickseed	0
1	Echinacea pallida	Pale Coneflower	-
1	Eupatorium maculatum	Joe Pye Weed	7
0.25	Heliopsis helianthoides	False Sunflower	-
0.50	Solidago nemoralis	Gray Goldenrod	-

0.25	Penstemon digitalis	Smooth White Penstemon	-
18 lbs / ac	**Wetland Meadow Mix**		
18 lbs / ac	**Overseed at Wetland Benches (after plant installation) (Additional Alternative)**		
5 lbs/ac	**PERENNIALS**		
1	Asclepies incameta	Swamp Milkweed	-
1.0	Eupatorium maculatum	Joe Pye Weed	-
0.5	Euthamia graminifolia	Grass Leaved Goldenrod	-
1	Lobelia cardinalis	Red Cardinal Flower	-
1	Onoclea sinsibilis	Sensitive Fern	5
0.5	Veronia novabora censis	Ironweed	5
10 lbs/ac	**Woodland Mix**		
3 lbs/ac	**PERENNIALS**		
0.5	Aster novae-angliae	New England Aster	-
0.5	Cimicifuga racemosa	Black Cohash	-
1	Desmodium canadense	Showy Tick Trefoil	-
1	Penstemon digitalis	Tall White Beard Tongue	-
15 lbs / ac	**Reforestation Mix**		
6 lbs/ac	**PERENNIALS**		
4	Trifolium repens	White Colver, Ladino	-
2	Chamaecrista fasciculata	Partridge Pea	-

Quantity/ Area	Scientific Name	Common Name	C
11 lbs / ac	**GRASSES**		
2	Andropogon ternarius	Splitbeard Bluestem	-
2	Bouteloua curtipendula	Side Oats Gamma	-
1	Eragrostis spectabilis	Purple Love Grass	-

4	Schizachyrium scoparium	Little Bluestem	-
1	Schoenoplectus pugens	Common Threesquare	-
1	Sporobolus asper	Rough Dropseed	-
18 lbs / ac	**Wetland Meadow Mix**		
18 lbs / ac	**Additional Overseed at Wetland Benches (after plant installation) - ADD ALTERNATE.**		
13 lbs/ac	**GRASSES**		
2	Carex composa	Cosmos Sedge	6
1	Carex lupulina	Hop Sedge	5
1	Carex stricta	Tussock Sedge	7
1	Chasmantiu latifolium	River Oats	-
1	Elymus virginicus	Virginia Wild Rye	5
2	Juncus effusus	Soft Rush	3
3	Panicum virgatum	Switchgrass	5
2	Scirpus cyperinus	Woolgrass Bulrush	3
10 lbs/ac	**Woodland Mix**		
7 lbs/ac	**GRASSES**		
2	Deschampsia flexulosa	Common Hair Grass	-
1	Elymus hystrix	Bottlebrush Grass	-
4	Elymus virginicus	Virginia Wild Rye	-
15 lbs / ac	**Reforestation Mix**		
9 lbs/a	**GRASSES**		
3	Elymus virginicus	Virginia Wild Rye	-
2	Bouteloua curtipendula	Side Oats Gamma	-
1	Eragrostis spectabilis	Purple Love Grass	-
3	Schizachyrium scoparium	Little Bluestem	-
18 lbs / ac	**Fescue Mix**		

10 lbs/ac	Southeast Native Grass Mixture # 2903 (from Seedland) *(Contains Virginia Wildrye, Purpletop, and Broomsedge)*		-
8 lbs/ac	Sheeps Fescue Grass		-

Appendix B

Birds

Since Duke Water Reclamation Pond was completed in 2015, the birding community in Durham has been actively tracking birds seen at Duke Pond, which is listed as a "birding hotspot" by eBird.org based on having at least 400 reported observations. Bird species most commonly observed include: Mallard, Belted Kingfisher, Great Blue Heron, Hooded Merganser, and Song Sparrow.

The Eastern Bluebird, another common visitor, was once threatened by habitat loss.

As of December 2019, the following species of birds have been observed:

ANSERIFORMES	Canada Goose
	Mallard
	Hooded Merganser
PODICIPEDIFORMES	Pied-billed Grebe
COLUMBIFORMES	Rock Pigeon
	Mourning Dove
CUCULIFORMES	Yellow-billed Cuckoo
CAPRIMILGIIFORMES	Common Nighthawk
	Chimney Swift
	Ruby-throated Hummingbird
CHARADRIIFORMES	Killdeer
	Spotted Sandpiper
SULIFORMES	Double-crested Cormorant
PELICANIFORMES	Great Blue Heron
	Great Egret
	Green Heron
ACCIPITRIFORMES	Black Vulture
	Turkey Vulture
	Sharp-shinned Hawk
	Cooper's Hawk

	Red-shouldered Hawk
	Red-tailed Hawk
CORACIIFORMES	Belted Kingfisher
STRIGIFORMES	Great Horned Owl
PICIFORMES	Yellow-bellied Sapsucker
	Red-bellied Woodpecker
	Downy Woodpecker
	Northern Flicker
PASSERIFORMES	Eastern Wood Pewee
	Eastern Phoebe
	Great Crested Flycatcher
	Eastern Kingbird
	White-eyed Vireo
	Red-eyed Vireo
	Blue Jay
	American Crow
	Fish Crow
	Northern Rough-winged Swallow
	Bank Swallow
	Barn Swallow
	Cliff Swallow
	Tree Swallow
	Carolina Chickadee
	Tufted Titmouse
	White-breasted Nuthatch
	Brown-headed Nuthatch
	Brown Creeper
	House Wren
	Carolina Wren

	Blue-gray Gnatcatcher
	Golden-crowned Kinglet
	Ruby-crowned Kinglet
	Eastern Bluebird
	Wood Thrush
	American Robin
	Gray Catbird
	Brown Thrasher
	Northern Mockingbird
	European Starling
	Cedar Waxwing
	House Finch
	Pine Siskin
	American Goldfinch
	Chipping Sparrow
	Field Sparrow
	Dark-eyed Junco
	White-throated Sparrow
	Song Sparrow
	Swamp Sparrow
	Eastern Towhee
	Red-winged Blackbird
	Brown-headed Cowbird
	Common Grackle
	Ovenbird
	Common Yellowthroat
	Northern Parula
	Palm Warbler
	Pine Warbler

	Yellow-rumped Warbler
	Yellow-throated Warbler
	Prairie Warbler
	Summer Tanager
	Scarlet Tanager
	Northern Cardinal
	Blue Grosbeak
	Indigo Bunting
	House Sparrow

Appendix C

Wood

Duke Forest managed the timber harvest that cleared several acres of mixed oak and pine Piedmont forest to make room for Duke Pond. Quantities of timber and distribution of lumber for the project, provided to the CSI research team by Duke Forest and Duke University Facilities Management, are listed below to supplement description of wood related to Benefits for Reused and Recycled Materials.

NOTE – TO BE ADDED

Appendix D

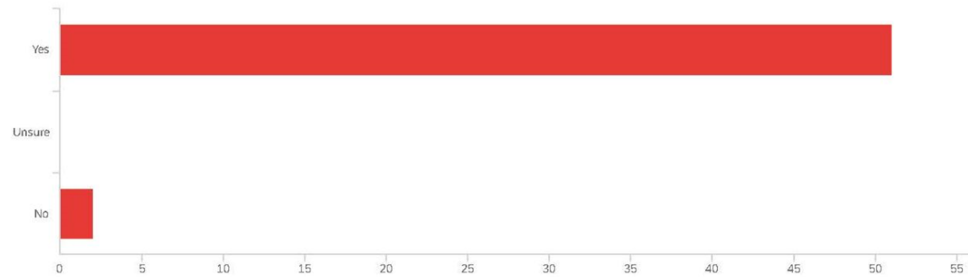
Survey Results

The 2020 CSI Survey intended to assess Social Benefits related to the implementation of Duke Pond. As an instrument, the survey builds on the on-going work by Mark Hough, Duke University Landscape Architect; Tavey McDaniel Capps, Sustainability Director for Sustainable Duke; and Dr. Curtis Richardson, Professor of Resource Ecology and Founding Director of the Duke University Wetland Center in the Nicholas School of the Environment, to promote the role of Duke Pond in the broader ecological and stormwater management mission of Duke University. Tavey has co-led ENV245 Sustainability Theory and Practice, which uses Duke Pond as one case study among several potential Campus Sustainability Research Projects. The CSI Survey questions align with and expand on previous surveys of the Duke University campus community, including those cited at the Social Benefits at the Case Study document, in order to facilitate comparison across the surveys.

Default Report

Pond Use Survey: LAF 2020 CSI Duke Water Reclamation Pond
February 5, 2021 9:56 AM MST

Q2 - Have you heard of Duke Pond prior to this survey?

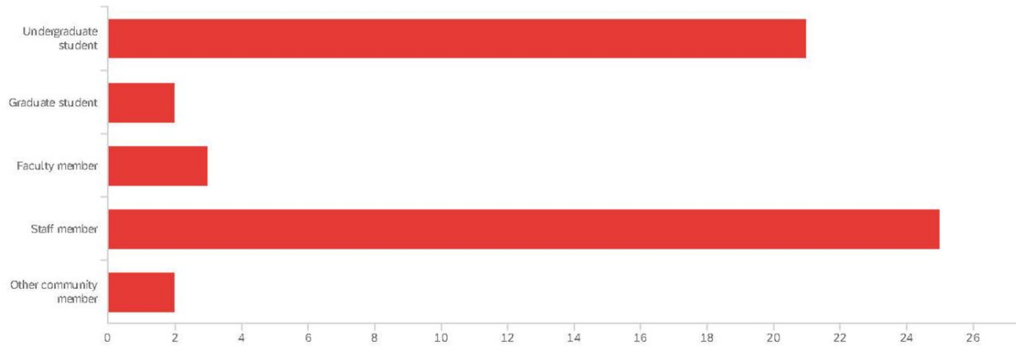


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Have you heard of Duke Pond prior to this survey?	1.00	3.00	1.08	0.38	0.15	53

#	Field		Choice Count
1	Yes	96.23%	51
2	Unsure	0.00%	0
3	No	3.77%	2
			53

Showing rows 1 - 4 of 4

Q4 - Please describe your relationship to Duke University: You are a/an:

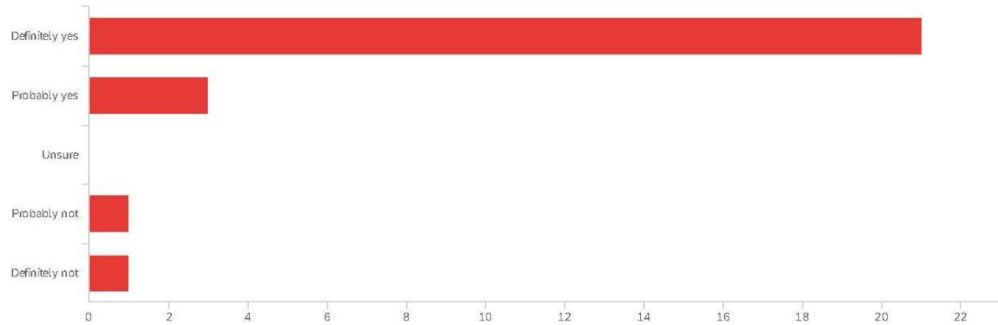


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Please describe your relationship to Duke University: You are a/an:	1.00	5.00	2.72	1.47	2.17	53

#	Field	Choice Count	
1	Undergraduate student	39.62%	21
2	Graduate student	3.77%	2
3	Faculty member	5.66%	3
4	Staff member	47.17%	25
5	Other community member	3.77%	2
			53

Showing rows 1 - 6 of 6

Q5 - Do you think of Duke's physical campus as a resource for your education, teaching, research, or other work?

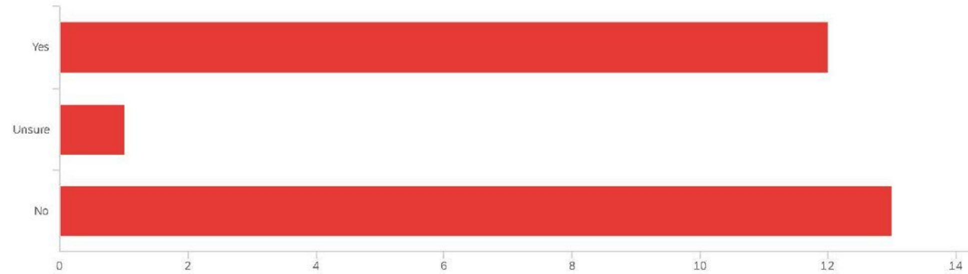


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Do you think of Duke's physical campus as a resource for your education, teaching, research, or other work?	1.00	5.00	1.38	0.96	0.93	26

#	Field	Choice Count	
1	Definitely yes	80.77%	21
2	Probably yes	11.54%	3
3	Unsure	0.00%	0
4	Probably not	3.85%	1
5	Definitely not	3.85%	1
			26

Showing rows 1 - 6 of 6

Q6 - Do you know Duke Pond is part of a sustainable storm water management project for the campus?

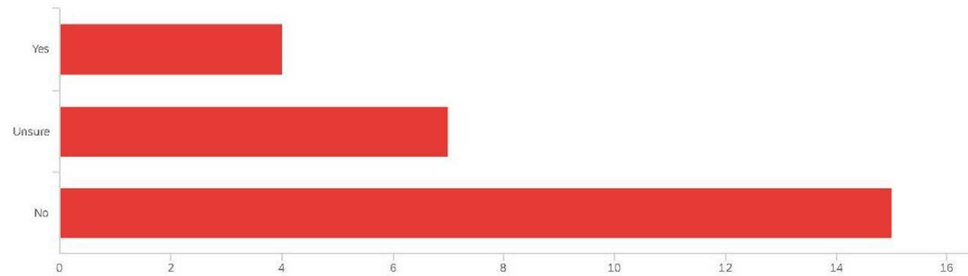


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Do you know Duke Pond is part of a sustainable storm water management project for the campus?	1.00	3.00	2.04	0.98	0.96	26

#	Field	Choice Count	
1	Yes	46.15%	12
2	Unsure	3.85%	1
3	No	50.00%	13
			26

Showing rows 1 - 4 of 4

Q7 - Are you aware of ways your program or school at Duke University is using the Pond landscape in your curriculum?

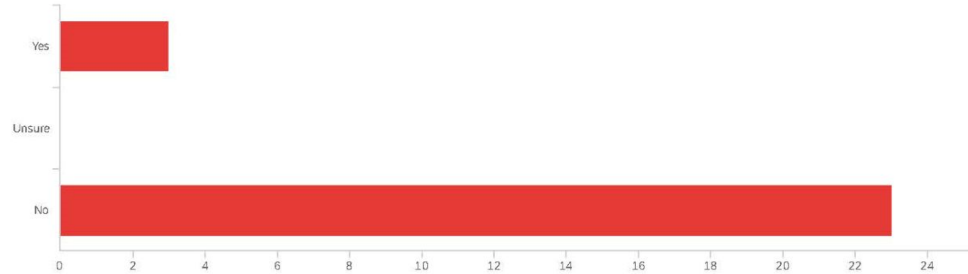


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Are you aware of ways your program or school at Duke University is using the Pond landscape in your curriculum?	1.00	3.00	2.42	0.74	0.55	26

#	Field	Choice Count	
1	Yes	15.38%	4
2	Unsure	26.92%	7
3	No	57.69%	15
			26

Showing rows 1 - 4 of 4

Q8 - Have you been involved in a class that used the Pond landscape?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Have you been involved in a class that used the Pond landscape?	1.00	3.00	2.77	0.64	0.41	26

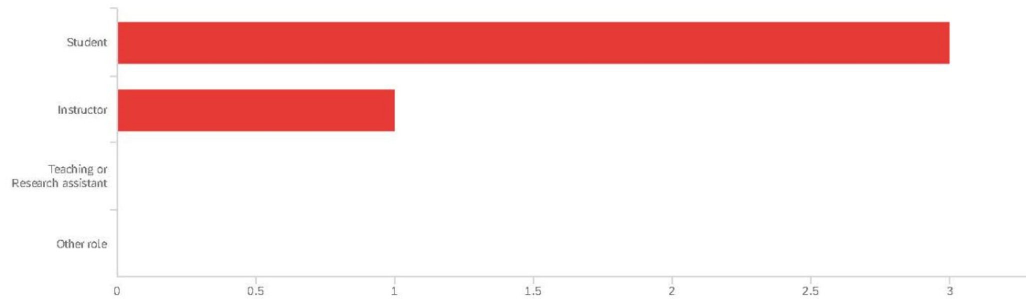
#	Field	Choice Count	
1	Yes	11.54%	3
2	Unsure	0.00%	0
3	No	88.46%	23
			26

Showing rows 1 - 4 of 4

Q9 - If you have been involved in a class that used the Pond landscape, what was the class?

If you have been involved in a class that used the Pond landscape, what was...
N/A
N/A
Water Resources
Sensory Physiology of Marine Animals
CE132, CE463, CE469

Q10 - If you have been involved in a class that used the Pond landscape, what was your role?

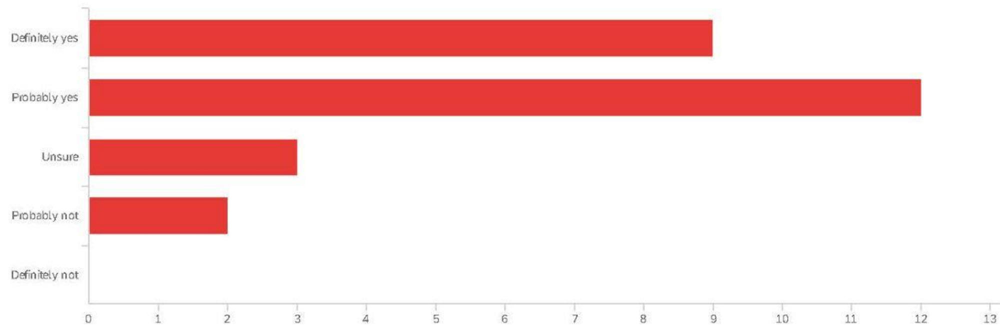


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	If you have been involved in a class that used the Pond landscape, what was your role?	1.00	2.00	1.25	0.43	0.19	4

#	Field	Choice Count	
1	Student	75.00%	3
2	Instructor	25.00%	1
3	Teaching or Research assistant	0.00%	0
4	Other role	0.00%	0
			4

Showing rows 1 - 5 of 5

Q11 - Would you participate in a class that used the Pond landscape if one was offered in your program or school?

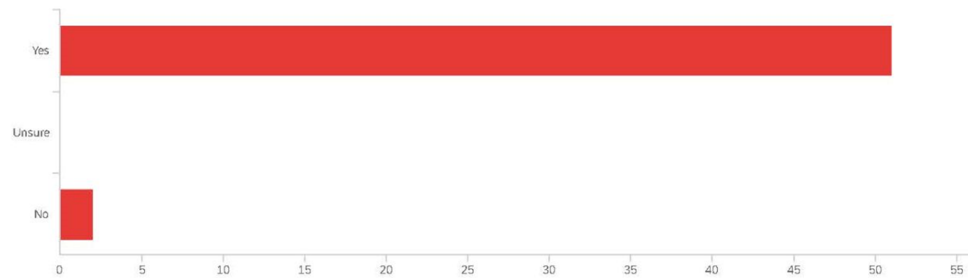


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Would you participate in a class that used the Pond landscape if one was offered in your program or school?	1.00	4.00	1.92	0.87	0.76	26

#	Field	Choice Count	
1	Definitely yes	34.62%	9
2	Probably yes	46.15%	12
3	Unsure	11.54%	3
4	Probably not	7.69%	2
5	Definitely not	0.00%	0
			26

Showing rows 1 - 6 of 6

Q13 - Have you ever seen or visited Duke Pond?

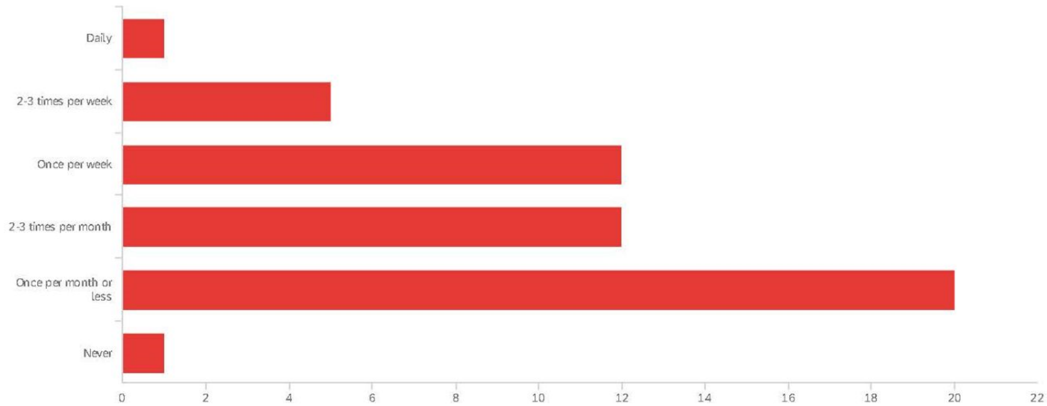


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Have you ever seen or visited Duke Pond?	1.00	4.00	1.11	0.57	0.33	53

#	Field		Choice Count
1	Yes	96.23%	51
3	Unsure	0.00%	0
4	No	3.77%	2
			53

Showing rows 1 - 4 of 4

Q14 - How often do you typically visit Duke Pond?

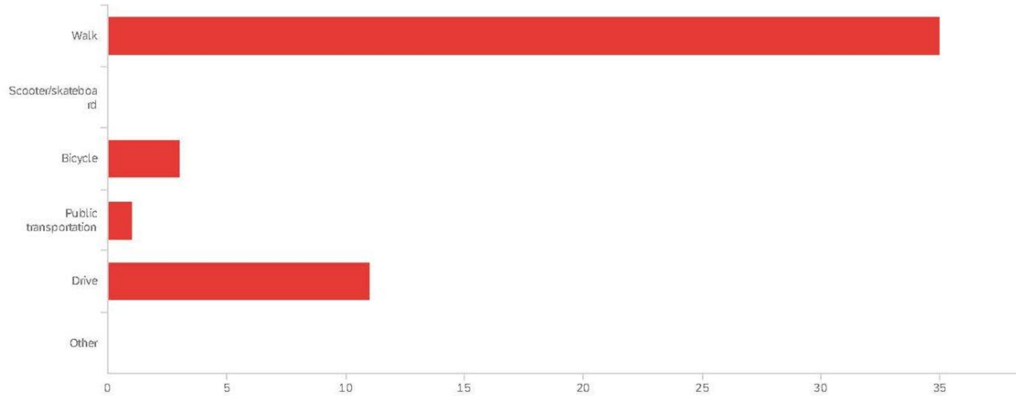


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do you typically visit Duke Pond?	1.00	6.00	3.94	1.13	1.27	51

#	Field	Choice Count	
1	Daily	1.96%	1
2	2-3 times per week	9.80%	5
3	Once per week	23.53%	12
4	2-3 times per month	23.53%	12
5	Once per month or less	39.22%	20
6	Never	1.96%	1
			51

Showing rows 1 - 7 of 7

Q15 - How do you typically arrive to the Pond?

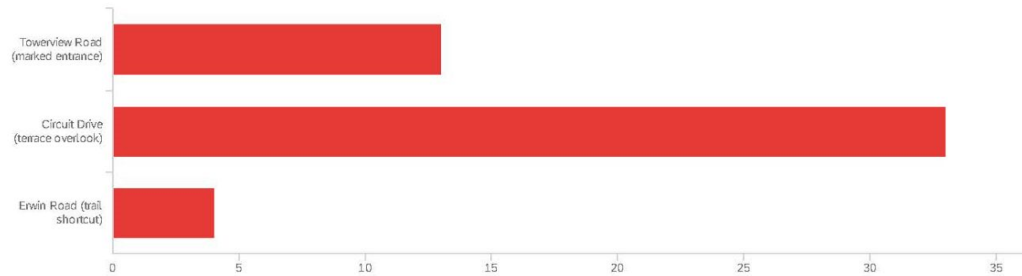


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How do you typically arrive to the Pond?	1.00	5.00	2.06	1.68	2.82	50

#	Field		Choice Count
1	Walk	70.00%	35
2	Scooter/skateboard	0.00%	0
3	Bicycle	6.00%	3
4	Public transportation	2.00%	1
5	Drive	22.00%	11
6	Other	0.00%	0
			50

Showing rows 1 - 7 of 7

Q16 - Access to Duke Pond is provided at Circuit Drive and Towerview Road. Where do you mainly enter the Pond landscape?

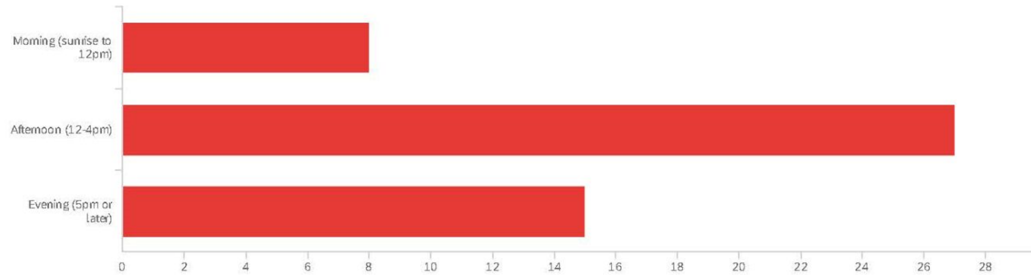


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Access to Duke Pond is provided at Circuit Drive and Towerview Road. Where do you mainly enter the Pond landscape?	1.00	3.00	1.82	0.55	0.31	50

#	Field	Choice Count	
1	Towerview Road (marked entrance)	26.00%	13
2	Circuit Drive (terrace overlook)	66.00%	33
3	Erwin Road (trail shortcut)	8.00%	4
			50

Showing rows 1 - 4 of 4

Q17 - When do you typically visit the Pond?

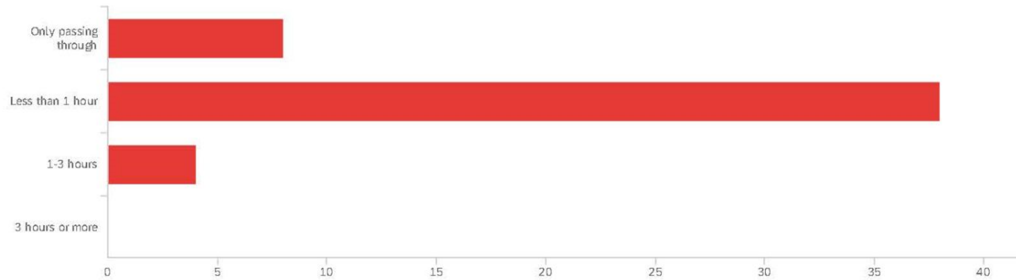


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	When do you typically visit the Pond?	1.00	3.00	2.14	0.66	0.44	50

#	Field	Choice Count	
1	Morning (sunrise to 12pm)	16.00%	8
2	Afternoon (12-4pm)	54.00%	27
3	Evening (5pm or later)	30.00%	15
			50

Showing rows 1 - 4 of 4

Q18 - How long do you stay at Duke Pond during a typical visit?

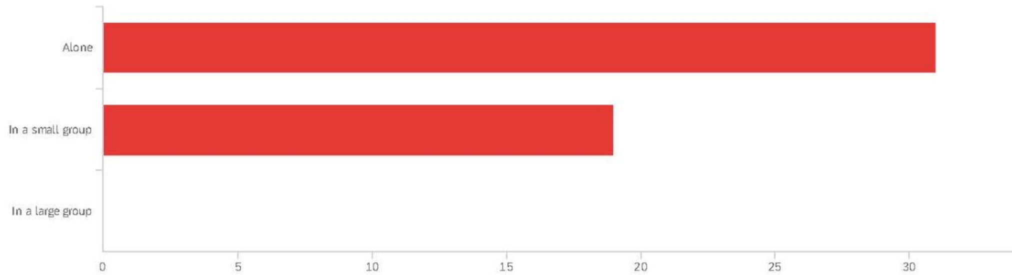


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How long do you stay at Duke Pond during a typical visit?	1.00	3.00	1.92	0.48	0.23	50

#	Field	Choice Count	
1	Only passing through	16.00%	8
2	Less than 1 hour	76.00%	38
3	1-3 hours	8.00%	4
4	3 hours or more	0.00%	0
			50

Showing rows 1 - 5 of 5

Q19 - Do you typically visit Duke Pond...

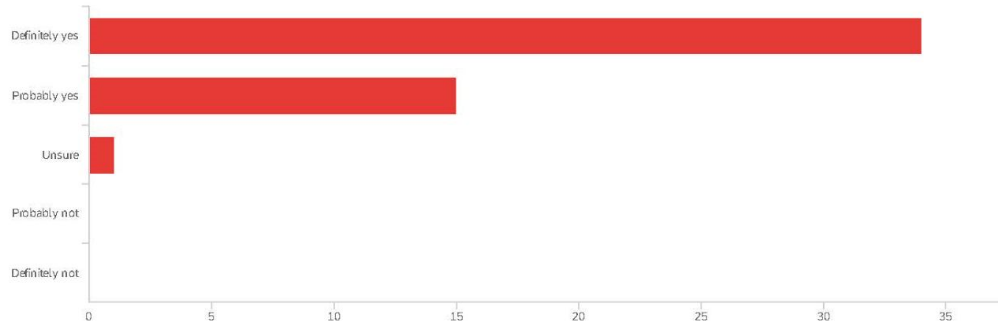


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Do you typically visit Duke Pond...	1.00	2.00	1.38	0.49	0.24	50

#	Field	Choice Count	
1	Alone	62.00%	31
2	In a small group	38.00%	19
3	In a large group	0.00%	0
			50

Showing rows 1 - 4 of 4

Q20 - Do you typically feel safe at Duke Pond?

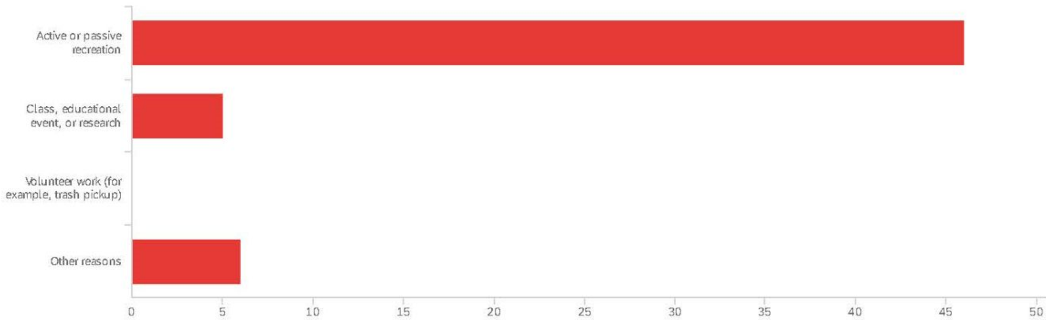


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Do you typically feel safe at Duke Pond?	1.00	3.00	1.34	0.51	0.26	50

#	Field	Choice Count	
1	Definitely yes	68.00%	34
2	Probably yes	30.00%	15
3	Unsure	2.00%	1
4	Probably not	0.00%	0
5	Definitely not	0.00%	0
			50

Showing rows 1 - 6 of 6

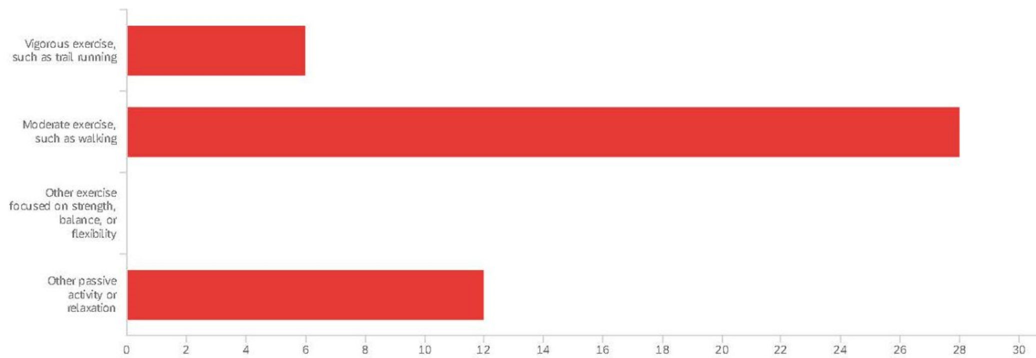
Q21 - Why do you primarily visit Duke Pond? (Select all that apply.)



#	Field		Choice Count
1	Active or passive recreation	80.70%	46
4	Class, educational event, or research	8.77%	5
9	Volunteer work (for example, trash pickup)	0.00%	0
10	Other reasons	10.53%	6
			57

Showing rows 1 - 5 of 5

Q22 - What type of activity or exercise do you typically do at Duke Pond?

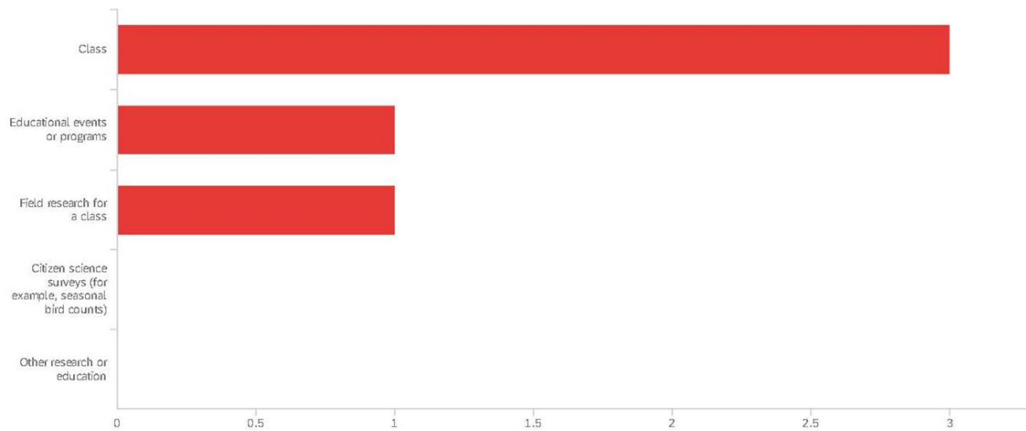


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	What type of activity or exercise do you typically do at Duke Pond?	1.00	4.00	2.39	1.01	1.02	46

#	Field		Choice Count
1	Vigorous exercise, such as trail running	13.04%	6
2	Moderate exercise, such as walking	60.87%	28
3	Other exercise focused on strength, balance, or flexibility	0.00%	0
4	Other passive activity or relaxation	26.09%	12
			46

Showing rows 1 - 5 of 5

Q23 - What type of educational activity do you typically participate in at Duke Pond?

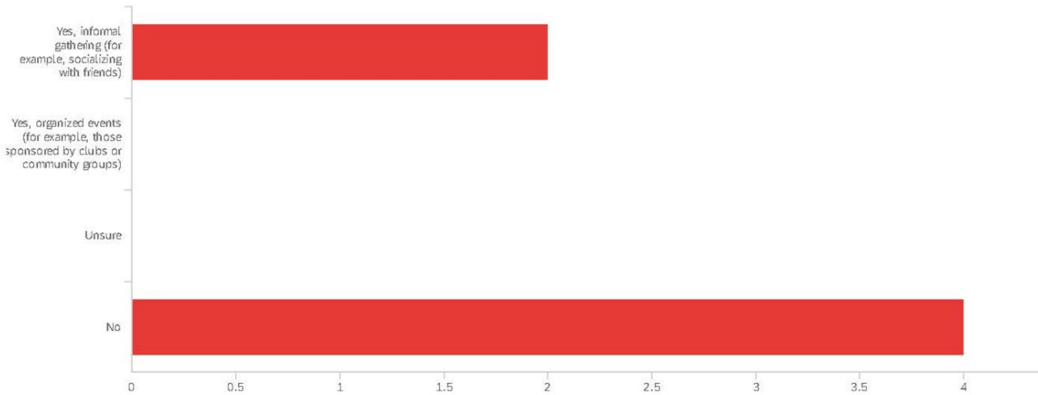


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	What type of educational activity do you typically participate in at Duke Pond?	1.00	3.00	1.60	0.80	0.64	5

#	Field	Choice Count	
1	Class	60.00%	3
2	Educational events or programs	20.00%	1
3	Field research for a class	20.00%	1
4	Citizen science surveys (for example, seasonal bird counts)	0.00%	0
5	Other research or education	0.00%	0
			5

Showing rows 1 - 6 of 6

Q24 - Do you socialize or attend social events at Duke Pond?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Do you socialize or attend social events at Duke Pond?	1.00	4.00	3.00	1.41	2.00	6

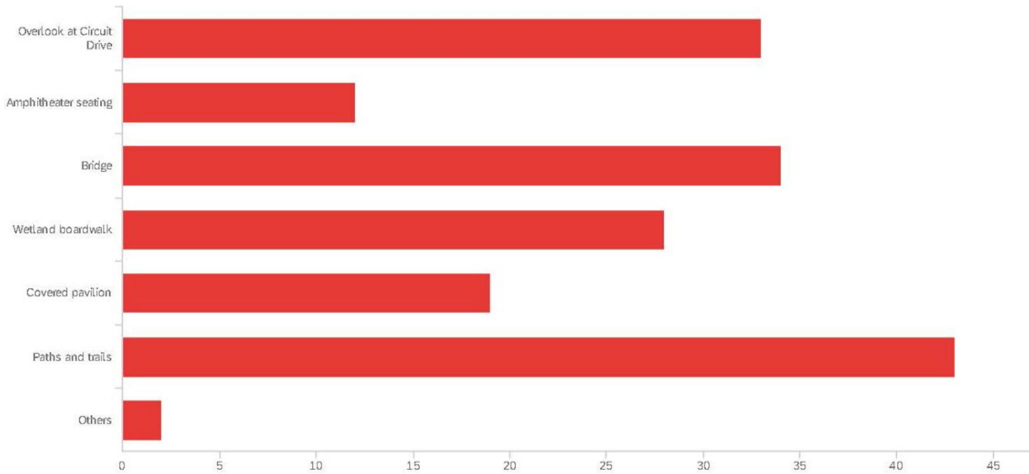
#	Field	Choice Count	
1	Yes, informal gathering (for example, socializing with friends)	33.33%	2
2	Yes, organized events (for example, those sponsored by clubs or community groups)	0.00%	0
3	Unsure	0.00%	0
4	No	66.67%	4
			6

Showing rows 1 - 5 of 5

Q25 - Who sponsored the event? (List school, club, or other group.)

Who sponsored the event? (List school, club, or other group.)

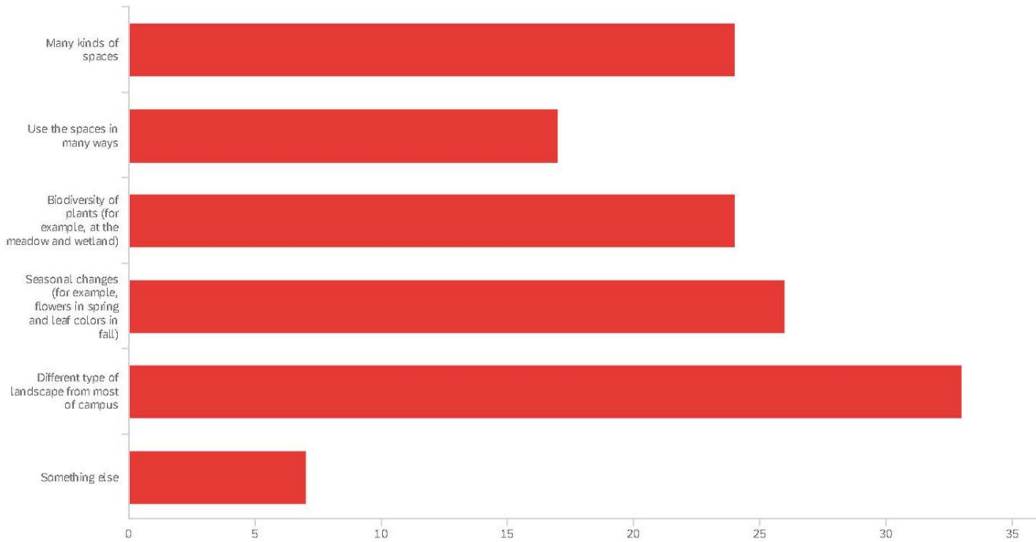
Q26 - What spaces do you typically visit at Duke Pond? (Select all that apply)



#	Field	Choice Count	
1	Overlook at Circuit Drive	19.30%	33
2	Amphitheater seating	7.02%	12
3	Bridge	19.88%	34
4	Wetland boardwalk	16.37%	28
5	Covered pavilion	11.11%	19
6	Paths and trails	25.15%	43
7	Others	1.17%	2
			171

Showing rows 1 - 8 of 8

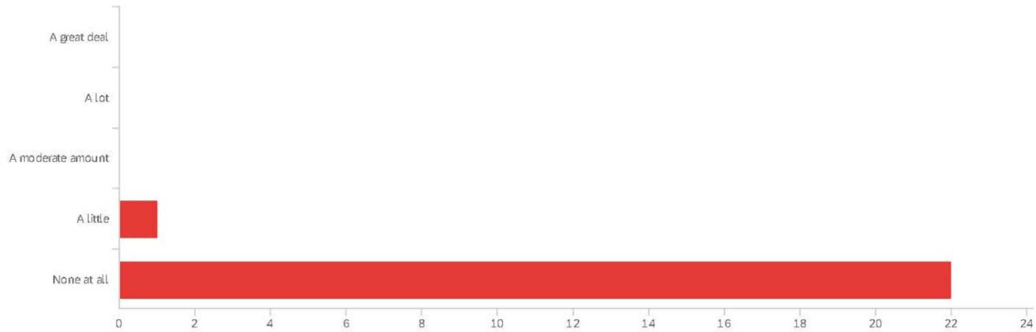
Q27 - Which of the following landscape elements at Duke Pond most appeals to you?



#	Field	Choice Count	
1	Many kinds of spaces	18.32%	24
2	Use the spaces in many ways	12.98%	17
3	Biodiversity of plants (for example, at the meadow and wetland)	18.32%	24
4	Seasonal changes (for example, flowers in spring and leaf colors in fall)	19.85%	26
5	Different type of landscape from most of campus	25.19%	33
6	Something else	5.34%	7
			131

Showing rows 1 - 7 of 7

Q28 - How much did Duke Pond influence your decision to attend Duke University?

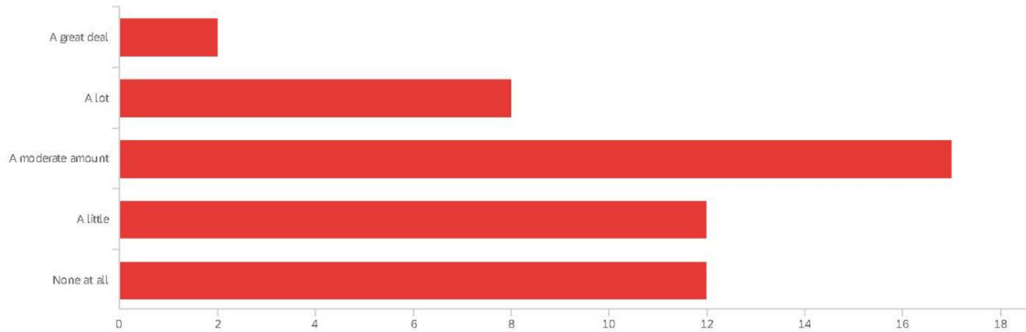


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How much did Duke Pond influence your decision to attend Duke University?	4.00	5.00	4.96	0.20	0.04	23

#	Field	Choice Count	
1	A great deal	0.00%	0
2	A lot	0.00%	0
3	A moderate amount	0.00%	0
4	A little	4.35%	1
5	None at all	95.65%	22
			23

Showing rows 1 - 6 of 6

Q29 - How much does Duke Pond contribute to your sense of "entering" the campus?

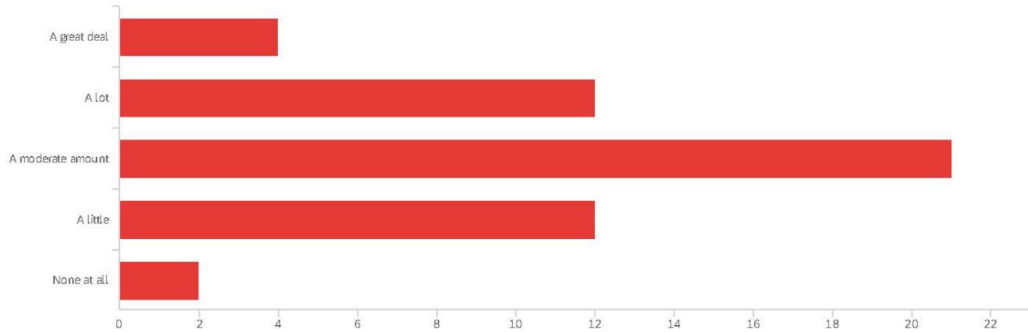


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How much does Duke Pond contribute to your sense of "entering" the campus?	1.00	5.00	3.47	1.13	1.27	51

#	Field	Choice Count	
1	A great deal	3.92%	2
2	A lot	15.69%	8
3	A moderate amount	33.33%	17
4	A little	23.53%	12
5	None at all	23.53%	12
			51

Showing rows 1 - 6 of 6

Q30 - How much has Duke Pond improved your experience of the Duke University campus?

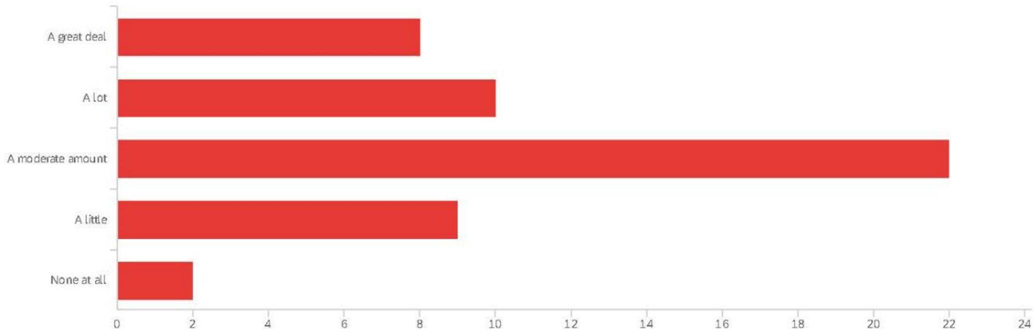


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How much has Duke Pond improved your experience of the Duke University campus?	1.00	5.00	2.92	0.97	0.94	51

#	Field		Choice Count
1	A great deal	7.84%	4
2	A lot	23.53%	12
3	A moderate amount	41.18%	21
4	A little	23.53%	12
5	None at all	3.92%	2
			51

Showing rows 1 - 6 of 6

Q31 - How much has Duke Pond improved your perception of the Duke University campus?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How much has Duke Pond improved your perception of the Duke University campus?	1.00	5.00	2.75	1.04	1.09	51

#	Field	Choice Count	
1	A great deal	15.69%	8
2	A lot	19.61%	10
3	A moderate amount	43.14%	22
4	A little	17.65%	9
5	None at all	3.92%	2
			51

Showing rows 1 - 6 of 6

End of Report