# Designing Decomposition: Reclaiming a Quarry for Carbon Sequestration




Rachel Rudd,
Associate Member ASLA
rachelrudd2357@gmail.com



## Summary

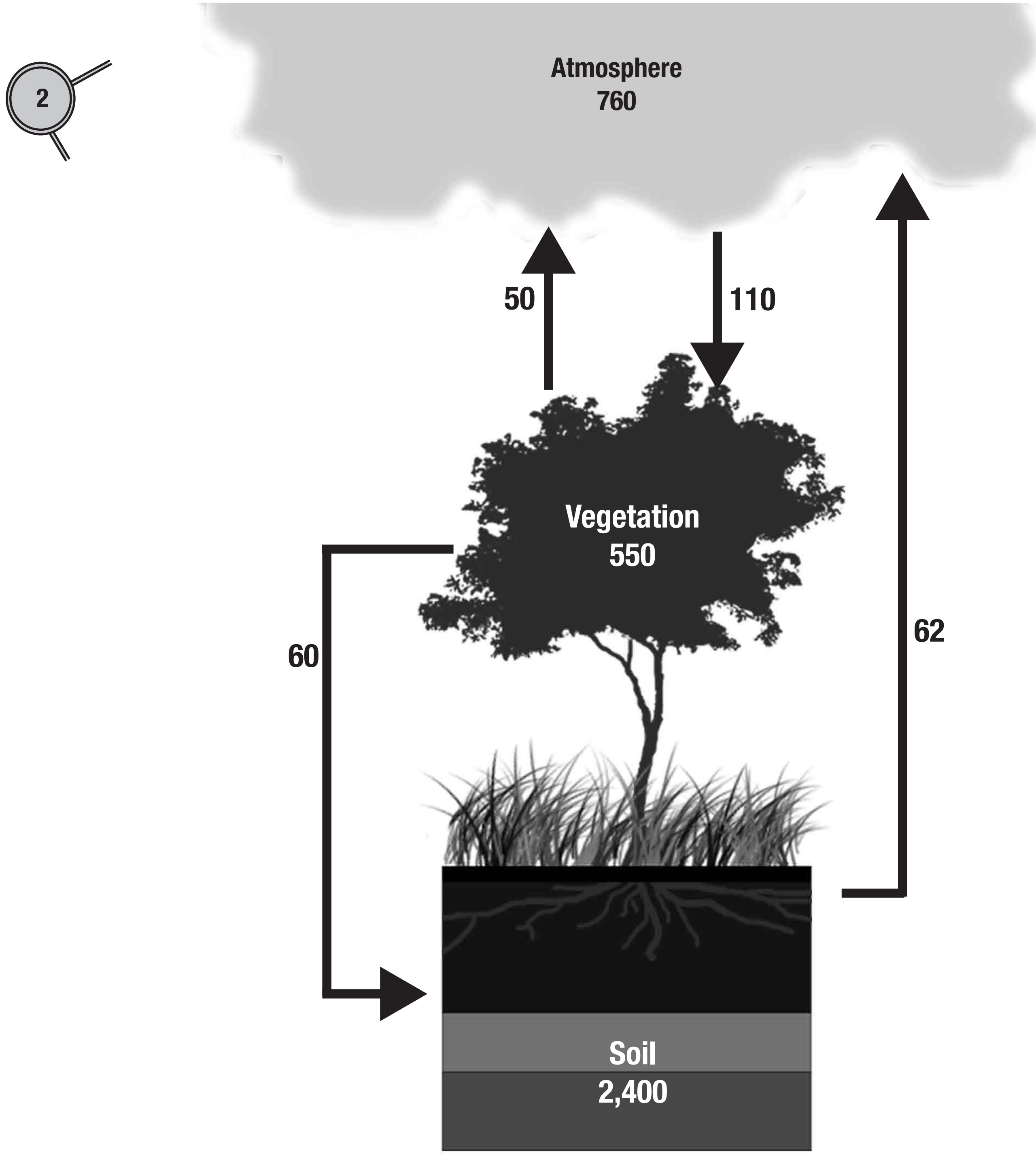
The Designing Decomposition study investigated the reuse of a retired quarry for carbon sequestration. The focus was on storage of carbon through: (1) large scale importation of organic landscape waste for decomposition and residuals storage, and (2) encouragement of soil sequestration of carbon with managed plant cover and manipulation the site's temperature and moisture through design interventions. The purpose was to create a dual purpose landscape: one that provides the community with a place for outdoor recreation and long-term carbon retention.

Designing Decomposition was envisioned as producing a landscape benefiting people and the environment. The idea was to change site capabilities by influencing the natural processes already taking place. Landscape Architects influence these natural processes in some way with every project. Quantifying the increase of ecosystem services a design produces could encourage more of these strategies to be used and could lead to inclusion in certification programs such as LEED or a credit system.

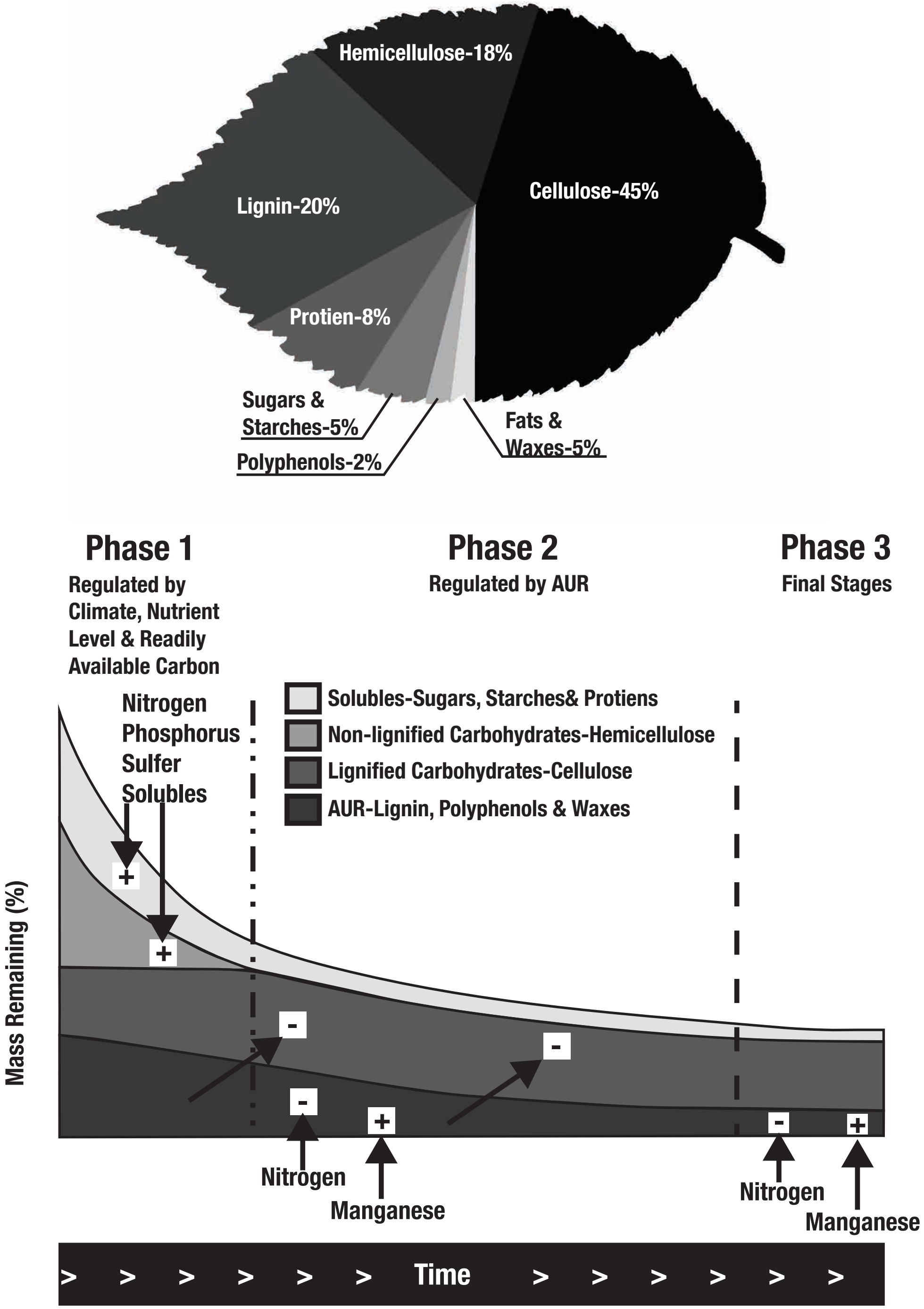
## Carbon, Vegetation & Soil

Soils have played a part in global climate change and can also play a part in carbon sequestration to slow it. In the past, soils held carbon in a pool (Lal & Follett, xi). This carbon has been transfered to the atmosphere as CO2 in the amount of 78 ± 12 Pg of carbon (Lal & Follett, xi). Most of this transfer of carbon has been due to cultivation and disturbance with the yearly rate of Carbon loss 1.6 ± 0.8 Pg (Smith, 2008). This means that soils are now a potential carbon sink, because they could hold the carbon that has recently been lost (Lal & Follett, xi).

Much of the carbon that could be sequestered in the soil could come from leaf litter. The annual deciduous tree leaf cycle has a large effect on the amount of carbon dioxide in the atmosphere. As trees photosynthesize, carbon dioxide is pulled out of the atmosphere. Some of this carbon is stored as new plant tissue. When the leaves fall there is an opportunity to sequester this carbon instead of microbes respiring it back into the atmosphere




Global Carbon Cycle. Numbers show the petagrams of carbon in different pools globally. Arrows show the annual movement of carbon between pools. Notice more carbon leaving the soil than entering each year.
Adapted From: Brady, Nyle C., and Ray R. Weil. The Nature and Properties of Soils. Prentice Hall, 2008. p. 497. Print.
Made in AdobeCS.




The Stages of Decomposition and the Parts of Leaf Litter Decomposed In Each. Adapted From: Brady, Nyle C., and Ray R. Weil. The Nature and Properties of Soils. Prentice Hall, 2008. p. 499. Print. & Berg, Björn, and Charles McClaugherty. Plant Litter: Decomposition, Humus Formation, Carbon Sequestration. Springer Science & Business Media, 2013. Print.
Made in AdobeCS.

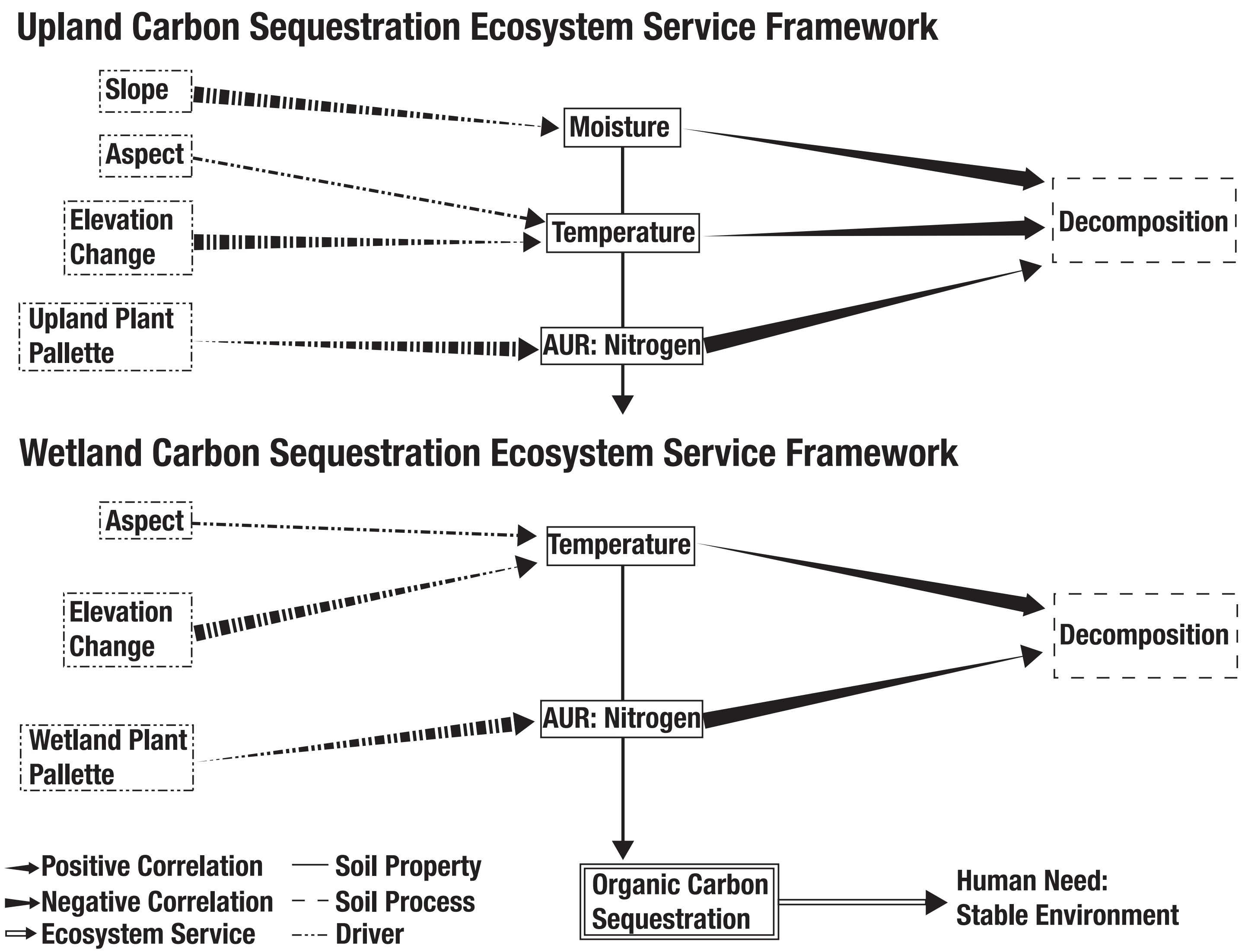
## Decomposition

Decomposition is the process by which large molecules are simplified into smaller parts (Brady & Weil, 500). It consists of three main stages, each regulated by different factors (Berg & McClaugherty, 15). The first stage of decomposition is regulated by climate, the amount of readily available carbon, and the amount of nitrogen, phosphorus, and sulfur (Berg & McClaugherty, 14-15). In this stage, more nutrients speed up the rate of decomposition as do increases in temperature and moisture (Berg & McClaugherty, 118, 144). The main parts of the litter that are decomposed at this time are water soluble carbon, and unlignified cellulose and hemicellulose (Berg & McClaugherty, 115). This stage typically ends when about 26-36% of the original litter mass is gone (Berg & McClaugherty, 115). The late stage of decomposition is regulated by the amount of AUR in the litter and also by nitrogen and manganese (Berg & McClaugherty, 123). The more AUR that is in litter the slower the rate of decomposition at this stage (Berg & McClaugherty, 123).

## Framework

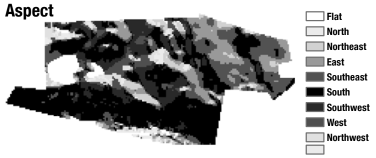
The next step in this study was to develop a framework to base the site analysis on. The central idea of this project was to increase the ecosystem service carbon sequestration through design, so I choose to model this framework on the Soil Ecosystem Service framework from Dominati, et. al. The framework shows how drivers, processes and properties interact to produce the flow of the ecosystem service carbon sequestration. This, in turn supports the human need of a stable environment.






Carbon Sequestration Ecosystem Service Framework shows how soil properties provide ecosystem services and are effected by processes and drivers.
Made in Adobe Illustrator

Aspect

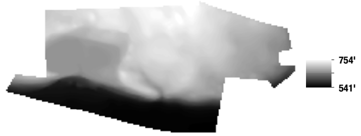



| Aspect | Temperature °C |
|---|---|
| South Site 1 | 12.7 |
| North Site 1 | 11.2 |
| South Site 2 | 12.6 |
| North Site 2 | 10.7 |

1.7 °C Average Difference Between North & South Slopes

From: Franzmeier, D.P. et al. "Properties of Some Soils in the Cumberland Plateau as Related to Slope Aspect and Position." Soil Science Society of America Proceedings 33.5 (1969): 755–761.

Elevation

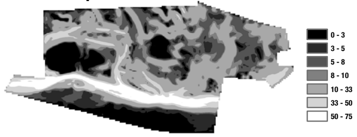



| Elevation | Temperature °C |
|---|---|
| 700-800 | 21.5-22.0 |
| 800-900 | 21.0-21.5 |
| 900-1000 | 20.5-21 |
| 1000-1100 | 19.5-20.5 |
| 1100-1200 | 19.0-19.5 |
| 1200-1300 | 18.5-19.0 |

0.015 °C Temperature Change for Every 10 Feet Elevation Change

From: Kang, S. et al. "Predicting Spatial and Temporal Patterns of Soil Temperature Based on Topography, Surface Cover and Air Temperature." Forest Ecology and Management 136.1 (2000): 173–184.

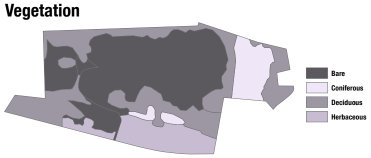
Percent Slope




| Slope | Infiltration Rate mm/s |
|---|---|
| 0% | $2.25 \times 10^{-2}$ |
| 15% | $1.92 \times 10^{-2}$ |
| 30% | $1.75 \times 10^{-2}$ |

From: Huat, Bujang B. K., Faisal HJ. Ali, and T. H. Low. "Water Infiltration Characteristics of Unsaturated Soil Slope and Its Effect on Suction and Stability." Geotechnical and Geological Engineering 24.5 (2006): 1293–1306.

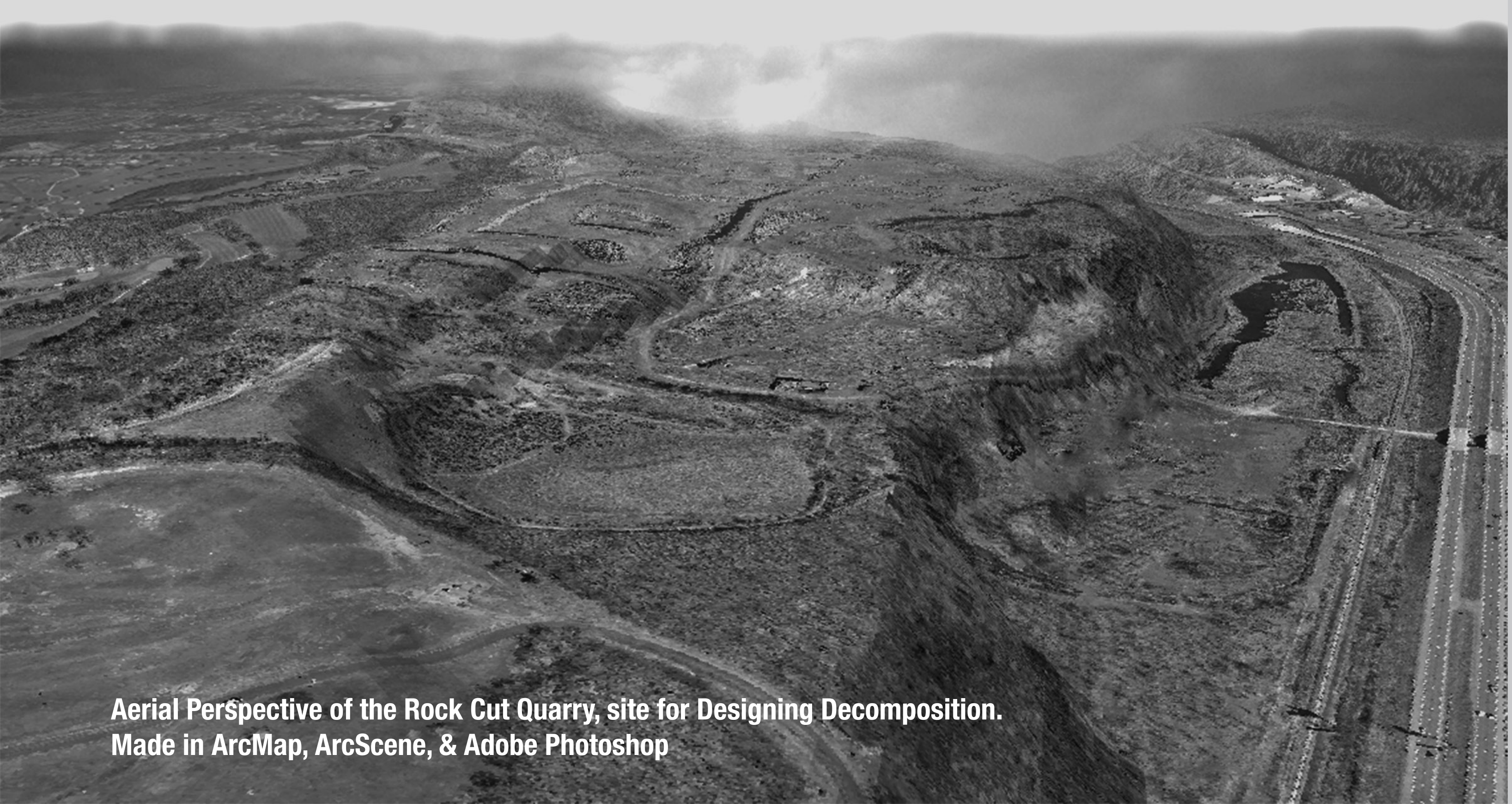
Vegetation




| Type | AUR:N |
|---|---|
| Evergreen | 53.4 |
| Deciduous | 27.8 |
| Herbaceous | 26.6 |
| All | 44.7 |

From: Berg, Björn, and Ryszard Laskowski. "DELILA II Database." Web.

Data creation process for Baseline Analysis. Data from published journal papers was merged with site information. Made in ArcMap, & Adobe Illustrator



Aerial Perspective of the Rock Cut Quarry, site for Designing Decomposition.
Made in ArcMap, ArcScene, & Adobe Photoshop

## Site: Rock Cut Quarry

The Rock Cut Quarry is located in Jamesville, New York and borders on Interstate 481 to the south, Drumlins Golf Club to the north and Syracuse University to the west. Clark Reservation State Park is also south of the site, across the interstate and Rock Cut Road. This quarry has not been in operation in about 15 years, and no rehabilitation has been carried out. The quarried part of the site is bare rock, and another large portion has been colonized by invasive plant species and weeds.

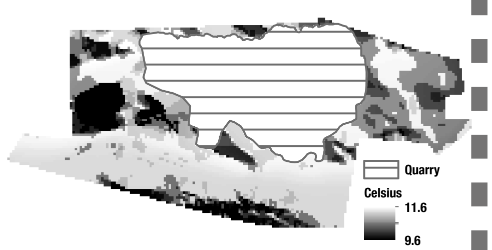
In order to complete a baseline analysis on the percent litter mass left after 3 years, I needed the site's temperature, moisture, and AUR:N properties. Because I was not able to collect field data from the site, I paired base layers for the drivers aspect, elevation, slope, and vegetation with data from primary literature, modifying the Quarry's average temperature, moisture, and AUR:N according to those drivers. Pairing the data from primary literature with the site's slope, aspect, elevation and vegetation, created the Temperature, Moisture, and AUR:N data.

## Baseline Analysis

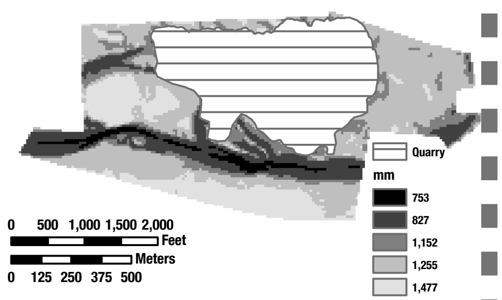
The temperature, moisture and AUR:N property layers were used in regression equations from the study by Moore, et al. to predict the mass of litter left after three years. I used the ArcGIS Spatial Analyst tool Raster Calculator to enter the regression equations and the data layers I created in the previous step. The analysis predicted that as things are today, litter that falls on this site will have 35.2% of it's mass remaining after three years. The wetland percentage was higher at 51.9% than the upland percentage at 34.6%. The next phase of this project was to create a design for a park that also increases the mass of litter remaining after 3 years.

Acid Unhydrolizable Residue:Nitrogen


Temperature: Variation From Elevation & Aspect




Precipitation:Variation From Slope

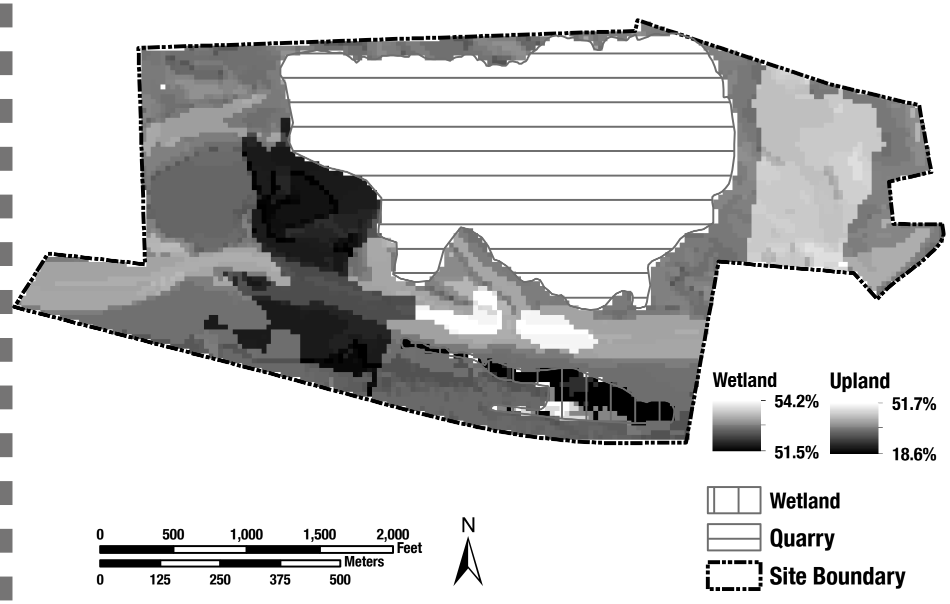



# Designing Decomposition: Baseline Analysis

| Weighted Mean Percent Litter Mass Left After 3 Years: | Upland Mean Percent Litter Mass Left After 3 Years: | Wetland Mean Percent Litter Mass Left After 3 Years: |
|---|---|---|
| 35.2% | 34.6% | 51.9% |

Regression Equations for Percent Mass After 3 Years:
Uplands: 59.52-(1.63*T)-(0.015*P)+(0.392*AUR:N)
Wetlands: 59.52-(1.63*T)+(0.392*AUR:N)

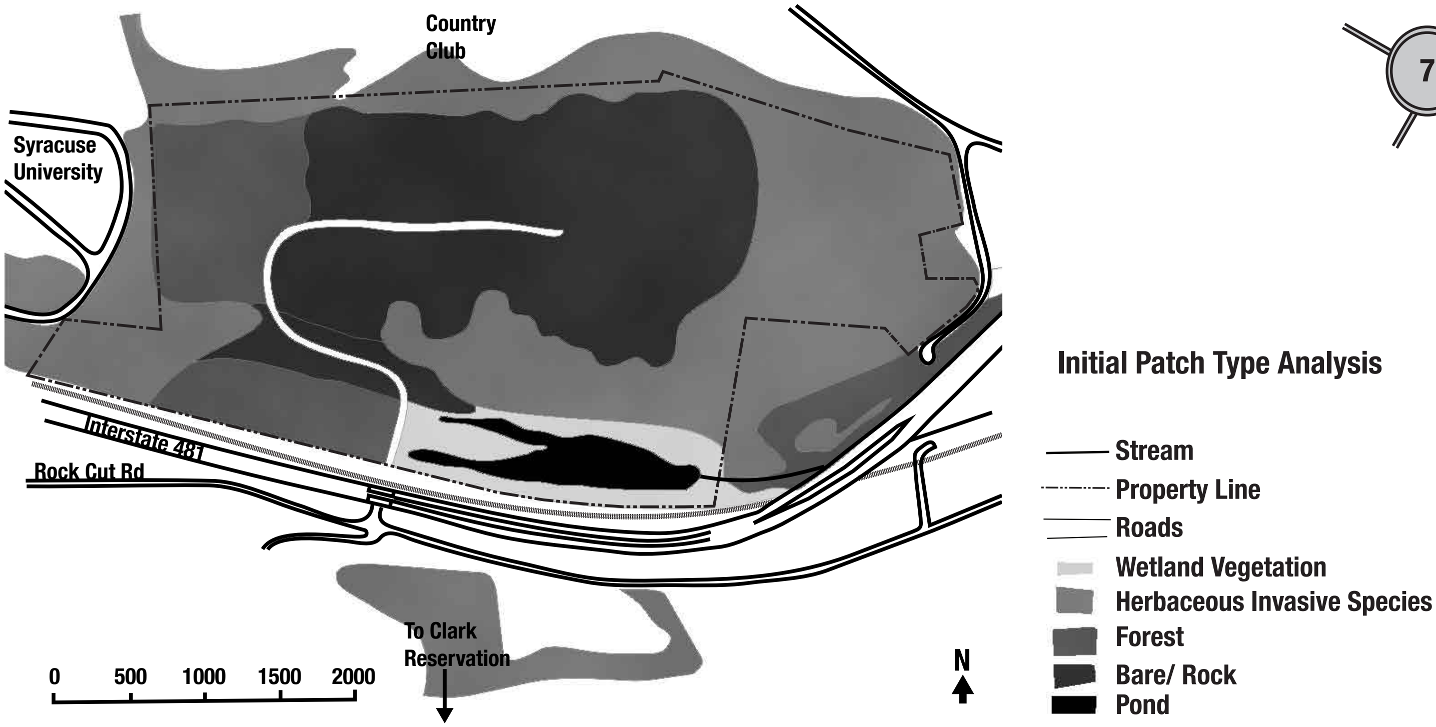
## Percent Litter Mass Left After 3 Years

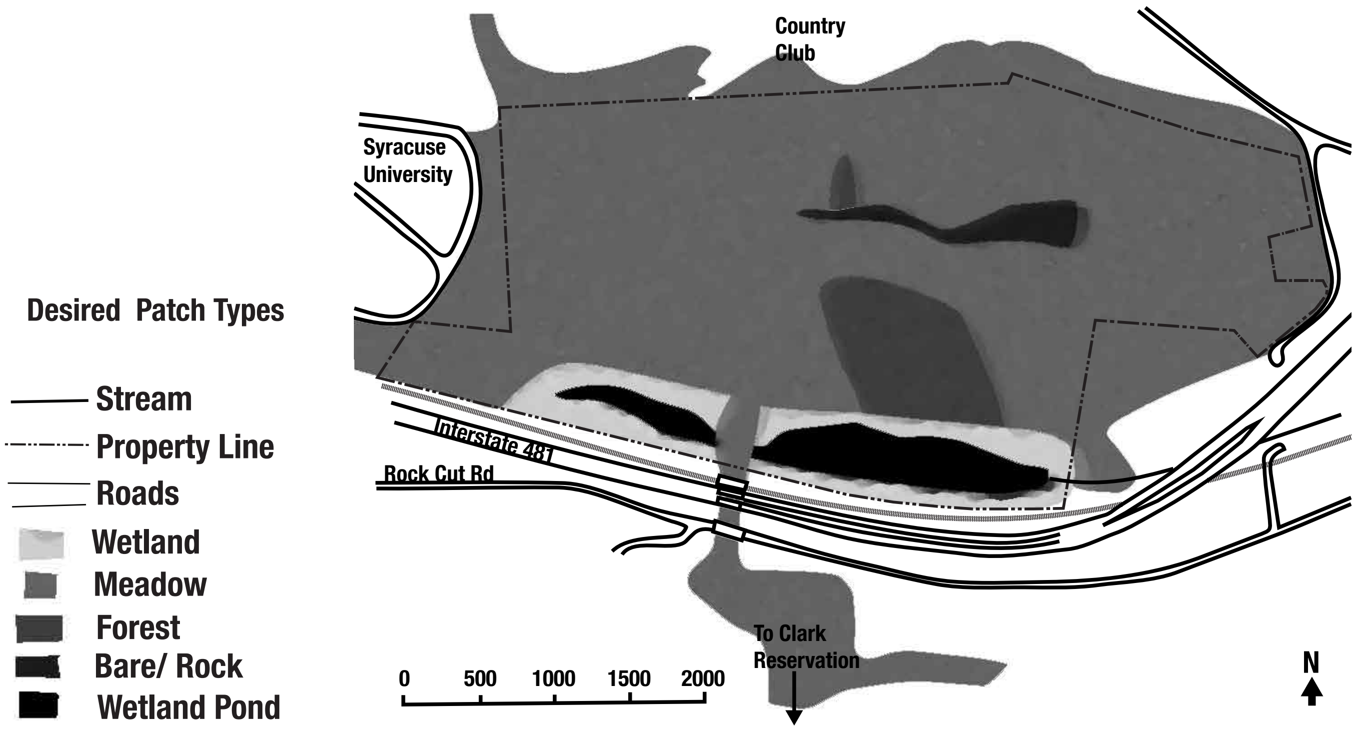



Baseline Analysis: shows the weighted mean for the mass of litter left after 3 years of decomposition on the site as well as the separate Upland & Wetland means. The quarried part of the site was excluded from the baseline analysis because it has no soil so cannot sequester carbon.

## Ecological Patches

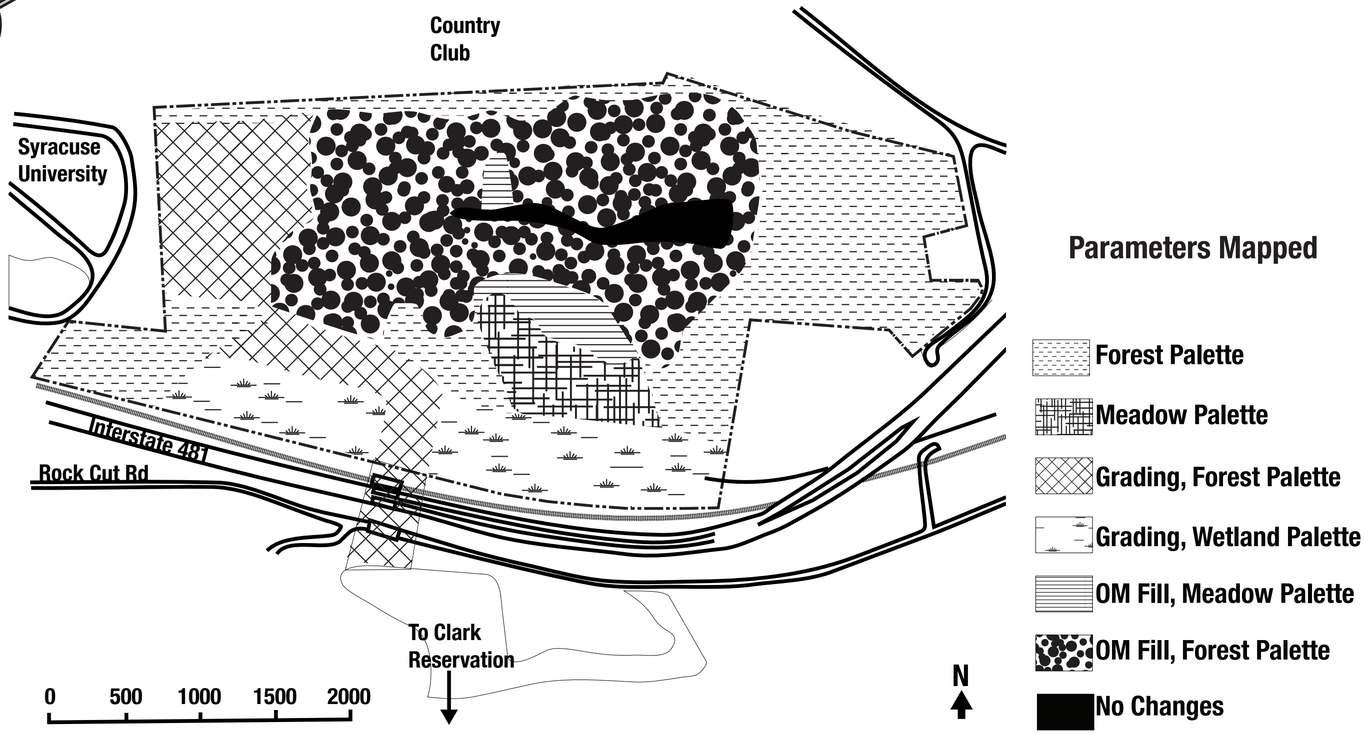
The design began with the evaluation of existing patches at the course scale of aerial photos. Simple categories were used such as Forest or Meadow to show where habitat was fragmented. Possible connections and constraints were considered as well. Then, the desired configuration of patches was developed based on what is known about areas having a slow decomposition rate. It was a main concern to create a continuous habitat with the exception of meadow habitat near viewpoints and a small portion of the original quarry.



## Parameters

Information about sites that are good at sequestering carbon was used to make design parameters to be applied to the existing patches on Rock Cut Quarry. The parameters state that if there is already a functioning forest in place, it should not be disturbed, but be planted using one of the plant palettes. In the quarry, where there is no soil, a long term filling operation is to take place using organic waste from Syracuse Department of Public Works. The filling operation will 1) create new “soil” where there is none and 2) sequester more carbon while doing it. If there is existing soil, but it cannot support vegetation due to compaction or has mostly invasive species then the area can be graded to make cooler temperatures and dryer conditions, and planted using the plant palettes. If there is an area at the toe of a slope, construct a wetland to catch any litter from up slope, which will decompose more slowly because of anaerobic conditions. Finally, like all ecosystems, Rock Cut Quarry will be more resilient and have more diversity if it is connected to other high functioning sites if possible.

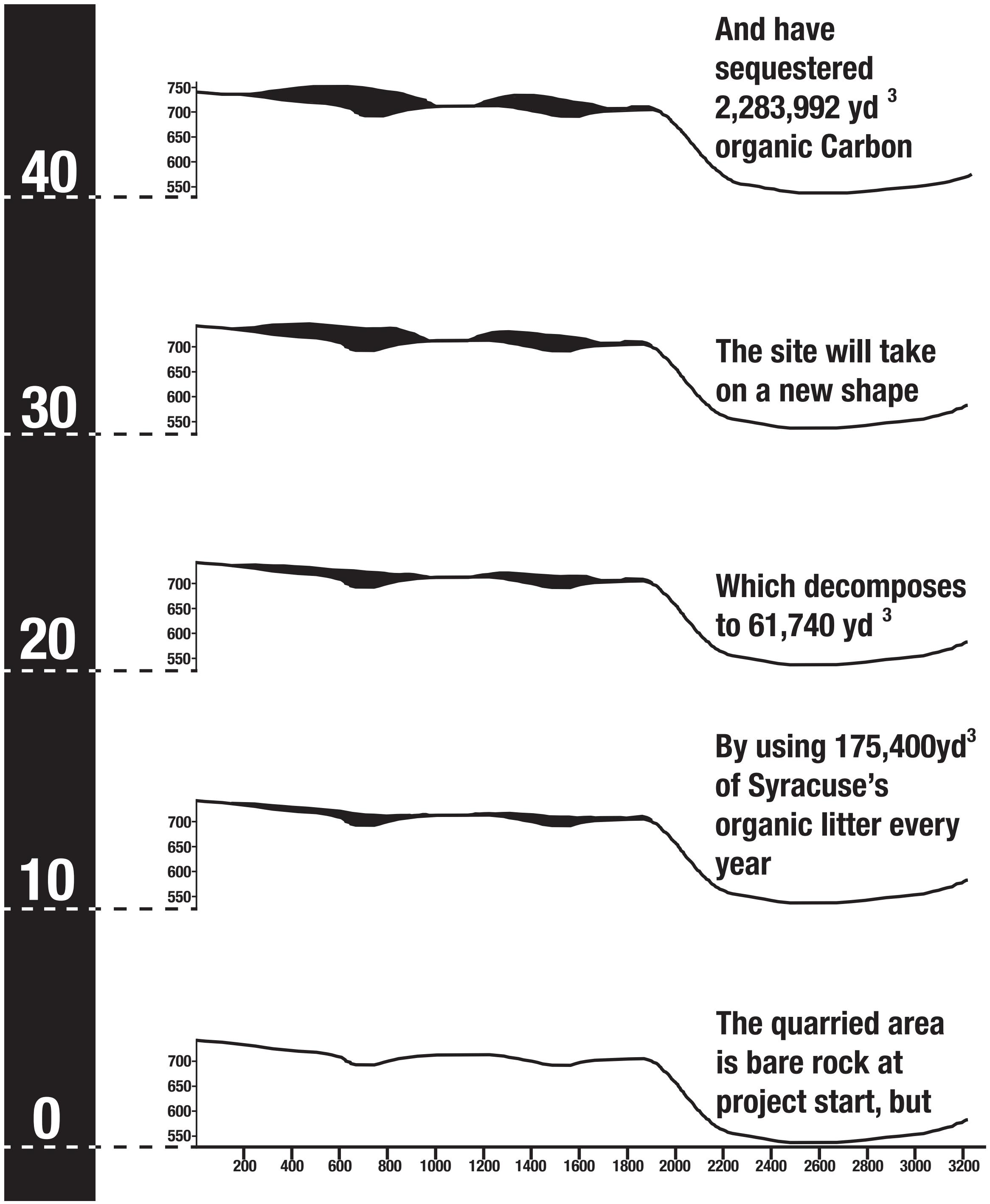



**Best Sites for Sequestration**

- Older Evergreen Forest Stands
- Cooler/Dryer (Aerobic)
- Wetlands (Anaerobic)
- Bottom of Slope

## Design Parameters

- If Functioning Forest: Then Use Plant Palettes to Increase AUR:N
- If No Soil Is Present: Then Fill with Organic Litter, Create Forest Using Plant Palette
- If Soil Is Bare or Has Mostly Invasive Species: Then Grade for Cooler Temperatures, Dryer Conditions, Use Plant Palettes to Increase AUR:N
- If Bottom of Slope: Then Create Wetland to Capture Litter From Upslope, Use Plant Palettes to Increase AUR:N
- If Similar High Quality Communities Nearby: Then Create Connections to Increase Biodiversity and Site Resilience.



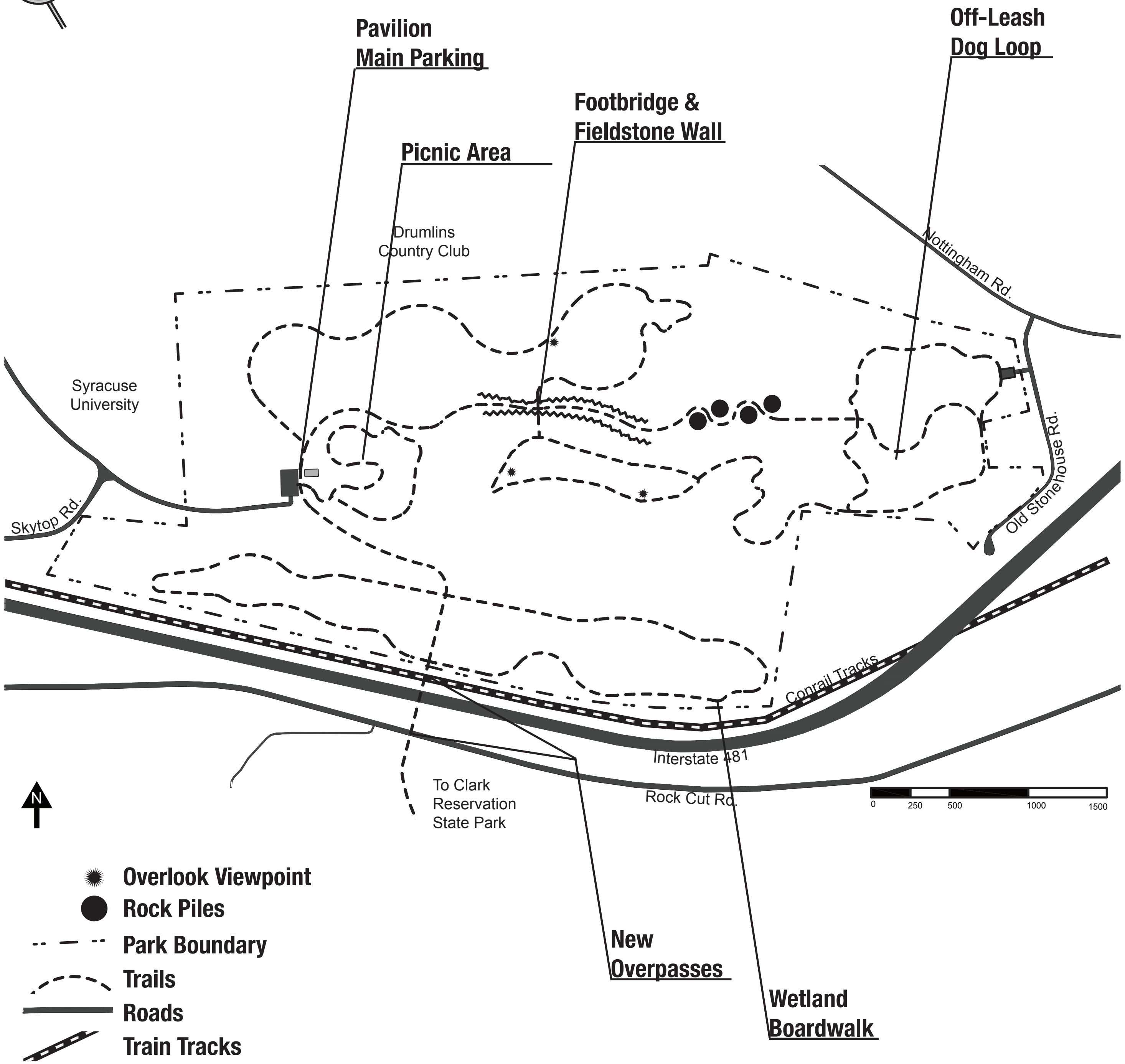

Rock Cut Quarry Organic Fill Operation Timetable
Made in ArcMap & Adobe Illustrator

## Organic Fill Operation

One of the design parameters was to fill the bare rock part of the site with leaf litter and wood chips from the Syracuse Department of Public Works and other organizations. After the organic matter in the now former quarry reached the correct elevation according to the grading plan, the filling operation could stop. At this time construction could begin on the rest of the design.

## Rock Cut Park Design

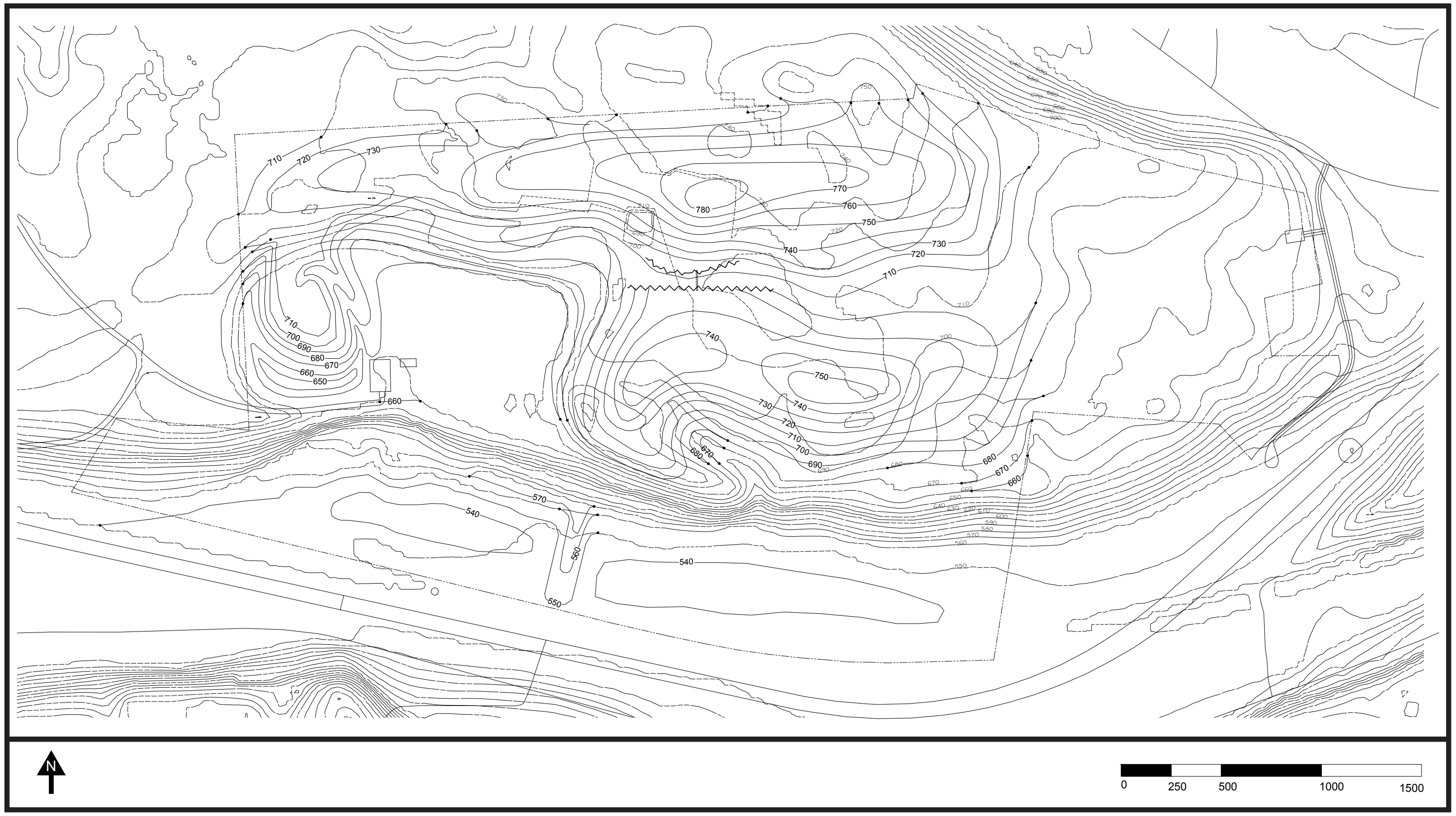
**The design of the Rock Cut Park was intended to provide recreation amenities for the community, encouraging a healthy lifestyle and filling some unmet recreation needs. The main activity for this park is hiking. The trail system meanders through a constructed wetland, forested ridges, and valleys. The trails feature overlook viewpoints, a footbridge, and a winding trail between fieldstone retaining walls topped by coniferous forest. A small piece of the former quarry remains as a reminder of what this place used to be, with a trail winding through large piles of rock. The park also features an unfenced off-leash dog area with wooded walking trails and a pavilion with adjacent picnic area. The Park would also extend across the train tracks, Interstate 481 and Rock Cut Road and into Clark Reservation, extending the available network of trails. This would be possible because of new overpasses. The park would be filling recreation needs of the community an also be providing the ecosystem service carbon sequestration and other important services.**




**Rock Cut Park Layout Plan**
**Made in AutoCAD & Adobe Illustrator**

## Grading Plan

**The site was graded according to the design parameters, leaving functioning forest intact and creating wetlands and cooler uplands where appropriate.**

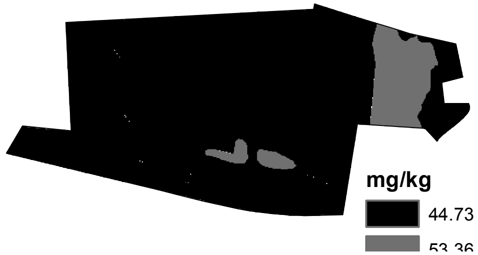



**Rock Cut Park Grading Plan**
**Made in AutoCAD**

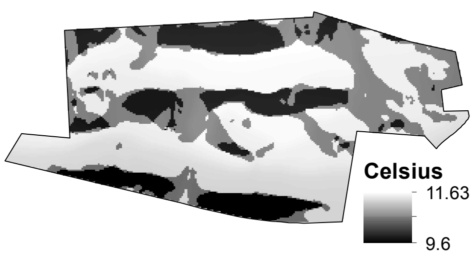
## Design Analysis

The Rock Cut Park design did increase the carbon sequestration potential of the site. After completion, the rate of decomposition on the site will have decreased by 6.2%. More work on this subject is important because as more accurate estimates of sequestration become available, they could support programs like California's cap and trade. For example, using the data from a 1971 study by Richard M. Hurd to calculate litter production, the entire Rock Cut Park would produce 316,065 kg/year of litter at the forest's maturity. After three years, 41.4% of the mass of that litter would still remain, leaving 130,851 kg litter mass, of which about 50% is carbon. To put this in perspective, in 2010 burning of fossil fuel and cement manufacturing produced 9.14 Petagrams of Carbon (Tyndall Centre for Climate Change). The Rock Cut Park would sequester about 0.000000065 Petagrams a year, plus the 0.0006 Petagrams from the filling quarry operation. This seems insignificant, but if more parks created and managed in this way it could help to slow climate change.

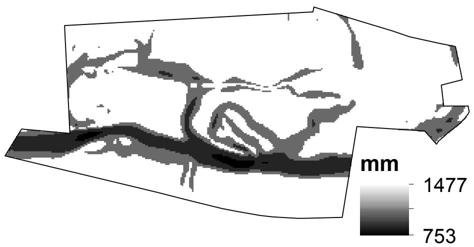
Acid Unhydrolizable Residue:Nitrogen




Temperature: Variation From Elevation & Aspect




Precipitation:Variation From Slope

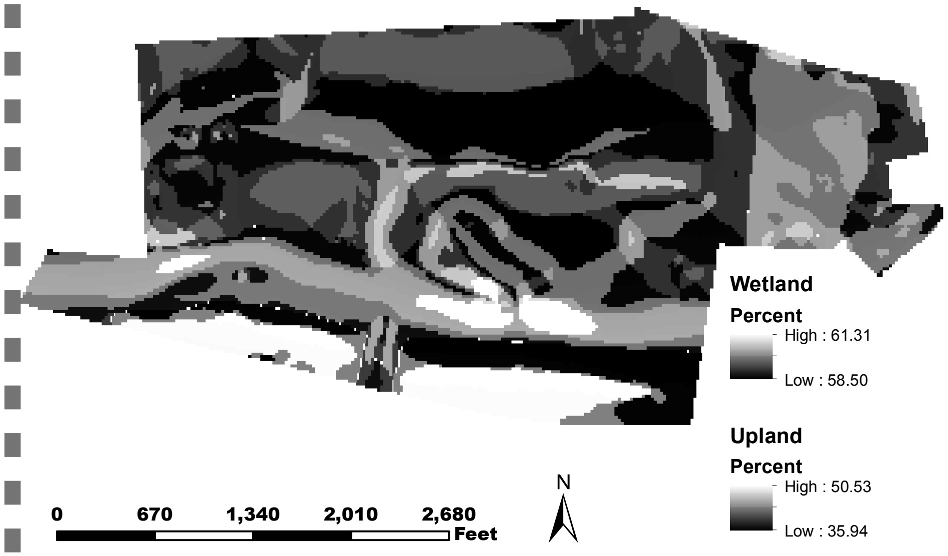



# Designing Decomposition: Design Analysis

| Weighted Mean Percent Litter Mass Left After 3 Years: | Upland Mean Percent Litter Mass Left After 3 Years: | Wetland Mean Percent Litter Mass Left After 3 Years: |
|---|---|---|
| 41.4% | 38.6% | 60.0% |

**Regression Equations for Percent Mass After 3 Years:**
Uplands: 59.52-(1.63*T)-(0.015*P)+(0.392*AUR:N)
Wetlands: 59.52-(1.63*T)+(0.392*AUR:N)

### Percent Litter Mass Left After 3 Years




Design Analysis: shows the weighted mean for the mass of litter left after 3 years of decomposition on the site as well as the separate Upland & Wetland means.
Made in ArcMap & Adobe Illustrator

Berg, Björn, and Ryszard Laskowski. “DELILA II Database.” : n. pag. Print.

Berg, Björn, and Charles McClaugherty. Plant Litter: Decomposition, Humus Formation, Carbon Sequestration. Springer Science & Business Media, 2013. Print.

Brady, Nyle C., and Ray R. Weil. The Nature and Properties of Soils. Prentice Hall, 2008. Print.

Brussaard, L. “Ecosystem Services Provided by the Soil Biota.” Soil Ecology and Ecosystem Services. Oxford University Press, 2012. 45–58. Print.

Cornelissen, J. H. C. “An Experimental Comparison of Leaf Decomposition Rates in a Wide Range of Temperate Plant Species and Types.” The Journal of
Ecology 84.4 (1996): 573. CrossRef. Web. 18 Nov. 2014.

Cornwell, William K. et al. “Plant Species Traits Are the Predominant Control on Litter Decomposition Rates within Biomes Worldwide.” Ecology Letters 11.10 (2008): 1065–1071. CrossRef. Web. 27 Oct. 2014.

Dominati, Estelle, Murray Patterson, and Alec Mackay. “A Framework for Classifying and Quantifying the Natural Capital and Ecosystem Services of Soils.”
Ecological Economics 69.9 (2010): 1858–1868. CrossRef. Web. 27 Oct. 2014.

Dwyer, L. M., and G. Merriam. “Influence of Topographic Heterogeneity on Deciduous Litter Decomposition.” Oikos 37.2 (1981): 228–237. Print.

Edmondson, Jill L. et al. “Land-Cover Effects on Soil Organic Carbon Stocks in a European City.” Science of The Total Environment 472 (2014): 444–453. CrossRef. Web. 4 Nov. 2014.

Franzmeier, D.P. et al. “Properties of Some Soils in the Cumberland Plateau as Related to Slope Aspect and Position.” Soil Science Society of America Proceedings 33.5 (1969): 755–761. Print.

“Global Carbon Budget 2010 | Tyndall°Centre for Climate Change Research ®.” N.p., n.d. Web. 24 Apr. 2015.

Harker, Donald. Landscape Restoration Handbook, Second Edition. CRC Press, 1999. Print.

Huat, Bujang B. K., Faisal HJ. Ali, and T. H. Low. “Water Infiltration Characteristics of Unsaturated Soil Slope and Its Effect on Suction and Stability.” Geotechnical and Geological Engineering 24.5 (2006): 1293–1306. CrossRef. Web. 12 Feb. 2015.

Hurd, Richard M. “Annual Tree-Litter Production by Successional Forest Stands, Juneau, Alaska.” Ecology 52.5 (1971): 881–884. JSTOR. Web. 24 Apr. 2015.

Intergovernmental Panel on Climate Change Working Group II. Climate Change 2014: Impacts, Adaptation, and Vulnerability. N.p., 2014. Print.

Intergovernmental Panel on Climate Change. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 2012. Print.

Jonasson, Sven, and Gaius R. Shaver. “Within-Stand Nutrient Cycling in Arctic and Boreal Wetlands.” Ecology 80.7 (1999): 2139–2150. Print.

Kang, S. et al. “Predicting Spatial and Temporal Patterns of Soil Temperature Based on Topography, Surface Cover and Air Temperature.” Forest Ecology and Management 136.1 (2000): 173–184. Print.

Lal, R., and Ronald F. Follett. Soil Carbon Sequestration and the Greenhouse Effect. ASA-CSSA-SSSA, 2009. Print.

Liu, Hongyan et al. “Topography-Controlled Soil Water Content and the Coexistence of Forest and Steppe in Northern China.” Physical Geography 33.6 (2012): 561–573. CrossRef. Web. 11 Feb. 2015.

Medvedeff, Cassandra A., Kanika S. Inglett, and Patrick W. Inglett. “Patterns and Controls of Anaerobic Soil Respiration and Methanogenesis Following Extreme Restoration of Calcareous Subtropical Wetlands.” Geoderma 245-246 (2015): 74–82. CrossRef. Web. 6 Mar. 2015.

Mestdagh et al. “Soil Organic Carbon Stocks in Verges and Urban Areas of Flanders, Belgium.” Grass & Forage Science 60.2 (2005): 151–156. EBSCOhost. Web. 4 Nov. 2014.

Mitsch, William J. et al. “Validation of the Ecosystem Services of Created Wetlands: Two Decades of Plant Succession, Nutrient Retention, and Carbon Sequestration in Experimental Riverine Marshes.” Ecological Engineering 72 (2014): 11–24. CrossRef. Web. 22 Apr. 2015.

Moore, T. R. et al. “Litter Decomposition Rates in Canadian Forests.” Global Change Biology 5.1 (1999): 75–82. EBSCOhost. Web. 19 Jan. 2015.

NOAA’s National Weather Service Binghamton, New York. “NOAA’s National Weather Service - Binghamton, NY - Syracuse, New York Annual Temperature, Precipitation, and Snowfall Data.” N.p., n.d. Web. 23 Apr. 2015.

Smith, Pete. “Land Use Change and Soil Organic Carbon Dynamics.” Nutrient Cycling in Agroecosystems 81.2 (2008): 169–178. CrossRef. Web. 4 Nov. 2014.

Soil Survey Staff. “Custom Soil Resource Report for Onondaga County, New York.” 10 Dec. 2015: n. pag. Print.

---. “Web Soil Survey.” Natural Resources Conservation Service, United States Department of Agriculture Print.

Stern, Nicholas. The Economics of Climate Change: The Stern Review. Cambridge University Press, 2007. Print.

Vesterdal, L, and K Raulund-Rasmussen. “Forest Floor Chemistry Under Seven Tree Species Along a Soil Fertility Gradient.” Canadian Journal of Forest Research 28.11 (1998): 1636–1647. Print.

Yavitt, Joseph B., and Christopher J. Williams. “Linking Tree Species Identity to Anaerobic Microbial Activity in a Forested Wetland Soil via Leaf Litter Decomposition and Leaf Carbon Fractions.” Plant and Soil (2015): n. pag. CrossRef. Web. 6 Mar. 2015.

## Appendix A:

### Upland Plant Palette

The Upland Plant Palette for trees was created by using community information on Pine-Northern Hardwood Forests from the NY Natural Heritage Program cross-referenced with Genus from the DELILA II Database. Herbaceous list was created using information from Cornwell, et al. with community information on Pine-Northern Hardwood Forests from the NY Natural Heritage Program. The species in this palette are meant to be keystone species for upland areas of Rock Cut Park.

| Scientific Name | Common Name |
| --- | --- |
| Trees | |
| *Abies balsamea* | Balsam Fir |
| *Betula papyrifera* | Paper Birch |
| *Picea rubens* | Red Spruce |
| *Pinus resinosa* | Red Pine |
| *Pinus strobus* | White Pine |
| *Quercus rubra* | Red Oak |
| *Tsuga canadensis* | Eastern Hemlock |
| | |
| Herbaceous | |
| *Carex pensylvanica* | Pennsylvania Sedge |
| *Deschampsia flexuosa* | Wavey Hair Grass |
| *Dryopteris intermedia* | Evergreen Woodfern |
| *Oryzopsis asperifolia* | Spreading Ricegrass |
| *Pteridium aquilinum* | Bracken Fern |

## Appendix B:

### Wetland Plant Palette

The Wetland Plant Palette for trees was created by using community information on Northern White Cedar Swamps from the NY Natural Heritage Program cross-referenced with Genus from the DELILA II Database (See Apendix C). Herbaceous list was created using information from Cornwell, et al. with community information on Northern White Cedar Swamps from the NY Natural Heritage Program. The species in this palette are meant to be keystone species for wetland areas of Rock Cut Park.

| Scientific Name | Common Name |
| --- | --- |
| Trees | |
| *Abies balsamea* | Balsam Fir |
| *Betula alleghaniensis* | Yellow Birch |
| *Larix laricina* | Tamarack |
| *Picea mariana* | Black Spruce |
| *Pinus strobus* | White Pine |
| *Thuja occidentalis* | Northern White Ceder |
| *Tsuga canadensis* | Eastern Hemlock |
| | |
| Herbaceous | |
| *Carex leptalea* | Bristly-stalk Sedge |
| *Carex trisperma* | Billings’ Sedge |
| *Glyceria striata* | Fowl Managrass |
| *Gymnocarpium dryopteris* | Northern Oak Fern |
| *Onoclea sensibilis* | Sensitive Fern |
| *Osmunda cinnamomea* | Cinnamon Fern |
| *Thelypteris palustris* | Marsh Fern |