OPTIMIZING ECOLOGICAL FUNCTION, AGRICULTURAL PRODUCTIVITY, AND AESTHETIC VALUE ON A SMALL SITE IN NEW JERSEY'S RURAL-URBAN FRINGE

By

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ABSTRACT OF THESIS

Optimizing Ecological Function, Agricultural Productivity, And Aesthetic Value on a Small Site in New Jersey's Rural-Urban Fringe

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Agricultural production can result in simplified plant communities, lower species diversity, and fragmented habitats. Farms in New Jersey's rural-urban fringe – where residential, agricultural, and wild fragments intermingle and a range of land use is accommodated – may offer an appropriate setting to enhance ecological function through landscape design. In particular, by applying principles of ecological design to small agricultural operations and hobby farms, ecological function, agricultural productivity and aesthetic value may all be enhanced. Through field experiments, research into historical land use and cover, in-depth analysis of present day natural features and processes, and exploration of case studies, a design was developed to enhance biodiversity, food production, and visual appeal on a one acre site in New Jersey's rural-urban fringe.

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INTRODUCTION

In his book, *Bringing Nature Home*, Douglas Tallamy describes the typical suburban landscape as “a highly simplified community consisting of a few species of alien ornamental plants that provide neither food nor shelter for animals” (Tallamy, 2009, p. 24). In more rural areas agricultural production can also result in simplified plant communities, lower species diversity, and fragmented habitats. Efforts to enhance ecological function in these settings are likely to encounter barriers that include aesthetic preference, regulations, and business concerns.

> Agriculture and development rank as the most frequent causes of habitat degradation. In urban areas the loss of wild habitat is apparent, but the fragmentation of habitat in rural areas is no less a problem…agriculture has caused the greatest loss of native insect populations. Farming and ranching practices may leave the landscape green, but those fields hold few food or nest resources and are often laden with pesticides. What little habitat is left – field margins, hedgerows, roadside banks, and the sides of ditches and creeks – is very important for pollinators, bus susceptible to drifting insecticides and hosts fewer of the native plant species that bees and other pollinators require (The Xerces Society, 2011, pp. 74–75).

Farms in the rural-urban fringe – where residential, agricultural, and wild fragments intermingle and a range of land use is accommodated – may offer an appropriate setting to enhance ecological function through landscape design. In particular, by applying principles of ecological design to small agricultural operations and hobby farms, ecological function and agricultural productivity may both be enhanced. For the purposes of this study, ecological design is defined as applying “knowledge of nature to create [a] high-performing landscape in which design goals and natural processes go hand in hand [and] life self-organizes and persists” (Beck & Franklin, 2013, pp. 4–5). Further, as the transition space between urban and rural, the rural-urban fringe holds some of the scenic appeal of rural areas and is likely to be seen by a greater number of travelers, possibly helping to increase the awareness, appreciation, and ultimately, uptake of ecological design.

Several trends may help support an ecological approach to agricultural production. There is a growing awareness that designed landscapes can, and perhaps, should enhance ecological function. In Van der Ryn's and Cowan's, *Ecological Design*, they state: "The first generation of ecological design was based on small-scale experiments with living lightly in place…The second generation of ecological design must effectively weave the insights of literally dozens of disciplines. It must create a viable ecological design craft with a genuine culture of sustainability" (Van der Ryn & Cowan, 2007, p. 47). There are also efforts underway to create "agricultural ecosystems that imitate natural systems in form and function while still providing for…human needs" (Shepard, 2013, p. xxii). "The Millenium Ecosystem Assessment (MA) documented the dominant impacts of agriculture on terrestrial land and freshwater use, and the critical importance of agricultural landscape in providing products for human sustenance, supporting wild species biodiversity and maintaining ecosystem services" (Scherr & NcNeely, 2007, p. 477). Landscape architects have also begun to apply "contemporary design and restoration ecology to working farms [in order to] develop a paradigm for the integrated production of agriculture, biodiversity, and beauty"(Nelson Byrd Woltz, 2017).

The goal of this project is to develop a process that combines the concepts of suitability analysis with the best practices of ecological design and ecological agriculture and apply them to a small site in order to optimize ecological function, agricultural productivity, and aesthetic value. It seeks to answer the question: can a site be designed to be an inviting and aesthetically pleasing space, given constraints of optimizing ecological soundness and agricultural productivity? The goals of the project are prioritized with ecological soundness as the primary goal, and agricultural productivity and aesthetic value as secondary goals. The long-term goal is to create a space that would inspire uptake of ecological design among other small farms and to develop a model approach that can be scaled and used throughout the region.

The first step of this project was to develop a comprehensive understanding of the historical land use of the study site and its current natural features and processes. Best practices for conducting this analysis were based on a literature review and interviews with experts in ecology, conservation agriculture, and landscape architecture. A field experiment was also conducted to provide additional information on the viability of various pollinator attracting ground covers.

A comprehensive catalogue of best practices and techniques for ecological and conservation agriculture design based on literature reviews, case study analyses, and interviews with experts was then developed. Based on this research, a design was created to enhance biodiversity and food production and create an inviting, visually appealing space.

HISTORY OF LAND USE AND LAND COVER IN STUDY SITE AREA

The character and ecology of the study site and surrounding areas are the products of ongoing human and non-human activities and processes. Fertile soils that originally supported dense forests, plentiful wildlife, and sparse human settlements, were eventually called into service for agricultural production and increasingly dense human settlement. Although the ecology and agriculture of the study site and surrounding areas has changed over time, land in the area is still predominantly forested or in agricultural production.

Location

The one acre study site is part of a 12.29 acre parcel located in Delaware Township, Hunterdon County, New Jersey. It is in the rural-urban fringe of New Jersey and is near Frenchtown and Lambertville, popular river town destinations. Because its scenic views and proximity to rivers, canals, and reservoirs, parks, nature preserves, and an extensive trail system, Hunterdon County and Delaware Township offer many opportunities for outdoor activities such as golf, canoeing, kayaking, boating, swimming, fishing, hunting, bird watching, equestrian sports, cycling, walking, running and hiking, motorcycling, sport aviation, and camping. The area is also a popular destination because of its Revolutionary War history, specialty and pick-your-own farms, museums, theaters, art galleries, restaurants and festivals. The regional and local character derives from this unique combination of scenic rural appeal, colonial architecture, and abundant waterways.

Delaware Township is bounded to the south by the City of Lambertville, Stockton Borough and the Delaware River, to the west and northwest by Kingwood Township, to the north by Franklin Township, northeast by Raritan Township, east by East Amwell

Township, and to the southeast by West Amwell Township. Delaware Township encompasses slightly more than 37 square miles and based on land area, is the third largest municipality in Hunterdon County. (Mulhall, 2004, p. 3) The study site property is bounded to the south by State Route 29, the Delaware and Raritan Canal, and the Delaware River. The D&R Canal, originally built to transport goods and coal to Philadelphia, is an important source of water for central New Jersey, a recreational resource, and is on the National Historic Register. (Regional Planning Partnership, 2001, p. 31) The section of Route 29 on which the parcel is located is designated as a Delaware River Scenic Byway, a New Jersey Scenic Byway, and National Scenic Byway and the section of the Delaware River on which it is located is designated as a Wild and Scenic River. To the east, the property straddles the Lockatong Creek, a tributary to the Central Delaware Watershed Management Area.

Figure 1: Study Site in Western New Jersey (Base map source: Google Earth, n.d.-a).

Settlement

The earliest Native Americans are thought to have inhabited Lenapehoking - the area that is now southeastern New York, New Jersey, eastern Pennsylvania, and northern Delaware – as early as 10,000 to 12,000 years ago (Kraft, 1987, p. 26). "The first real evidence of the presence of the human species in the state [of New Jersey] is derived from Indian artifacts found along the upper Delaware River Valley. These have been scientifically dated, indicating their use about 7,000 years ago" (Collins & Anderson, 1994, p. 54). A survey conducted between 1912 and 1915 identified four hundred and sixty-two Lenape camps, villages, burial sites and rock shelters within Hunterdon County and several camp and village sites located in the general area of the study site (Hunterdon County Cultural & Heritage Commission, 2014, p. 3).

The Indians of the area "hunted, fished, collected shellfish, and gathered wild vegetable foods. The dog was their only domesticated animal and they did not farm until sometime between 1000 B.C. and A.D. 1600 (Kraft, 1987, p. 52). During the period from 1000 B.C to A.D. 1600, the Woodland Indians of the area began to supplement their hunting, fishing and gathering with simple gardening. "The upper Delaware River valley is ideally suited for Indian-style horticulture. Its alluvial soils are free of stones, well drained and fertile. Dew collects nightly and helps to moisten plants and soils, and the temperature rarely gets so unbearably hot that plants wither" (Kraft, 1987, p. 118).

Fields were cleared by removing trees and burning underbrush and seeded with maize, beans and squash. Gardens were generally small, located near dwellings, and abandoned when the soil was exhausted. New plots were then started in another location or another section of forest cleared. The process of clearing forest is described further by Collins and Anderson:

> In the course of living in New Jersey, the Indians disturbed the natural vegetation. Sites had to be cleared for villages and for the cultivation of agricultural crops, particularly maize. The Indians cut the forests extensively to provide the wood and bark used for utensils, weapons, canoes, shelters, and especially for fuel. In addition to destroying forests in some locales, the Indians modified its composition in larger areas, mostly by setting fires (Collins & Anderson, 1994, pp. 54–55).

European settlement of the area brought with it the concept of land ownership which transformed the land. The first purchase of Hunterdon County land was made in 1688, the last in 1758 (Hunterdon County Cultural & Heritage Commission, 2014, p. 5). Land purchases by and conflicts with European settlers displaced the Lenape, the majority of whom eventually migrated west to Ontario, Wisconsin, Kansas and Oklahoma (Kraft, 1987, p. 236) "Although the Indians undoubtedly left some imprints on the landscape of New Jersey, it was the European settlers and their descendants who truly disturbed the vegetation of the state" (Collins & Anderson, 1994, p. 56). European settlers continued the Lenape practice of clearing forests with fire. Areas unsuitable for cultivation were used as sources of wood for fuel and shelter and domestic animals were allowed to graze freely in the woodlands. "By the time New Jersey became a state in 1778, no extensive areas of land well suited to farming remained wooded in the central part of the state" (Collins & Anderson, 1994, p. 56).

Early farms in the county were generally small, and farming practices generally wasteful, with farmers depleting the resources of one farm and moving to another to repeat the process. Eventually, fertilizers such as wood ash and lime were integrated into agricultural practices and farming practices improved. Soil erosion was a problem with early farming in the area and it wasn't until the late 1800's that the use of cover crops began (Hunterdon County Cultural & Heritage Commission, 2014).

Timber from nearby forests was used for fencing and split rail worm fences made of Chestnut were among the earliest fences built in the area. Live hedge fences of English and American white hawthorn and Osage Orange were also popular. Latter, barbed wire, electric fencing, particularly for cattle, and woven wire fencing, primarily for poultry, were used (Hunterdon County Cultural & Heritage Commission, 2014).

With the exception of buckwheat, the grains grown by present day Hunterdon farmers – corn, wheat, oats, and rye – are almost the same as those grown in Colonial days. Hay was originally derived from native grass, but eventually early European settlers introduced and included timothy and clover. Soy beans were introduced in the late 1800's and potatoes and tomatoes were commercially grown during the same period (Hunterdon County Cultural & Heritage Commission, 2014).

Apples and peaches were produced by many farms in the county and excess apples were distilled into applejack by local distilleries (Hunterdon County Cultural & Heritage Commission, 2014, p. 48, 133). Over time, however, the number of commercial orchards declined sharply due to an increase in pests and pathogens that interfered with apple production (Hunterdon County Cultural & Heritage Commission, 2014).

County farms also produced cattle for meat and milk, oxen and horses for work animals, swine for meat, and sheep for wool and occasionally meat"(Hunterdon County Cultural & Heritage Commission, 2014, p. 49). In the mid-60's, dairy and poultry were the major agricultural products of the county. In addition, horse farms showed growth during the mid-60's with increasing numbers of Thoroughbred and Standardbred breeding farms along with recreational horse farms (Hunterdon County Cultural & Heritage Commission, 2014, p. 58-60).

In the mid-1980s, conversion of farmland for residential and industrial use drove up land values in the county resulting in a growth of intensive, specialty agricultural operations (i.e., fruit, berries, vegetables, nursery stock, Christmas trees, and vineyard/wineries) which primarily sell directly to customers. These operations frequently include public recreational opportunities as part of their offerings. Although the increase in residential land use provides a larger local market, non-farm income for small, specialty farms – or government subsidies for conventional operations – is generally needed for farms to remain economically viable (Hunterdon County Cultural & Heritage Commission, 2014, pp. 59–61).

Delaware Township Profile

Present day settlement patterns suggest trends about potential future land use and development pressure. An important implication of increasing development for the site and the township is its impact on water availability and quality. Development also has the potential to further fragment ecosystems, reduce biodiversity, drive up the cost and challenges of farming (ex. fencing, insurance, complaints from neighbors), and reduce the rural character and appeal of the site and surrounding area.

According to the Delaware Township Comprehensive Farmland Preservation Plan, agricultural land has decreased 11 percent between 1986 and 2007, while urban land use was up 50 percent. However, the majority – 73 percent – of the land remains in agricultural and forested land. The following table is based on NJDEP Land Use/Land Cover data:

	1986		1995		2002		2007		Change	
	Acres	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Agricultural	10,733	45.	10,169	43	9,637	41	9,522	40	-1,210	-11
Barren Land	71	0	84	0	108	0	154	1	83	116
Forest	7,892	33	7,915	33	8,055	34	7,885	33	-7	0
Urban	2,346	10	2,898	12	3,277	14	3,522	15	1,176	50
Water	343	1	343	1	422	2	434	2	91	27
Wetlands	2,305	10	2,280	10	2,190	9	2,173	9	-132	-6
TOTAL	23,689	100	23,689	100	23,689	100	23,689	100	0	0

Table 1. Change in Delaware Township's Land Use/Land Cover (Delaware Township Committee and Planning Board, 2007, p. 37).

Delaware Township's population has more than doubled since 1930, when 1,704 people lived in the municipality (Maser Consulting P.A., 2012, p. 4). According to 2010 Census data, the total population of the township was 4,563, 98 percent white, with a median age of 48.6 years (Maser Consulting P.A., 2012, p. 5). Median household income in 2010 was $104,643 with the majority of the employed population employed in the non-farm sector. Agricultural employment is estimated to have increased between 2010, when 42 people were employed in "agriculture, forestry, fishing and hunting, and mining," and 2015, when 85 people were estimated to be employed in that sector (U. S. Census Bureau, n.d.).

Study Site

Historic aerial photographs show that the site, property, and surrounding areas have been wooded or in agricultural production since at least the 1930's.

Figure 2: Study Site (in yellow) amid Farm Fields in 1940 (NETRonline: Historic Aerials, n.d.)

The parcel includes a one acre home site, approximately 5.5 acres of harvested cropland, 1 acre of permanent pasture, and 4.79 acres of appurtenant woodland, part of which is in a conservation and drainage easement that creates a buffer around the Lockatong Creek with flows through the property. The area to be addressed is the orchard in the southern-most area of the property which is made up of prime agricultural soil. It is approximately 300-400’ from the Delaware River and downhill of a ridgeline.

Adjacent land to the east is partially wooded, partially cultivated residential property. To the west is a commercial nursery and winery. Recent removal of a vegetative buffer, reveals an extremely large and unsightly mulch and composting operation, as well as an equipment and supply yard. Adjacent property to the north is wooded and in hay production.

Until November 2015, the property, like the surrounding properties, was under New Jersey Farmland Assessment. It was withdrawn from the program in order to transition to permaculture because the program's annual income requirement is much easier to achieve through annual crop production than through permaculture, at least initially. Re-enrollment in the program is an option and will depend on agricultural productivity in the future.

Based on historical information and present day observation of the surrounding areas, it is likely to revert to Eastern Deciduous Forest if left untended. This suggests that the land may be able to support a mix of vegetation more likely to be found in forest edge conditions, which in turn could support enhanced biodiversity as well as food production.

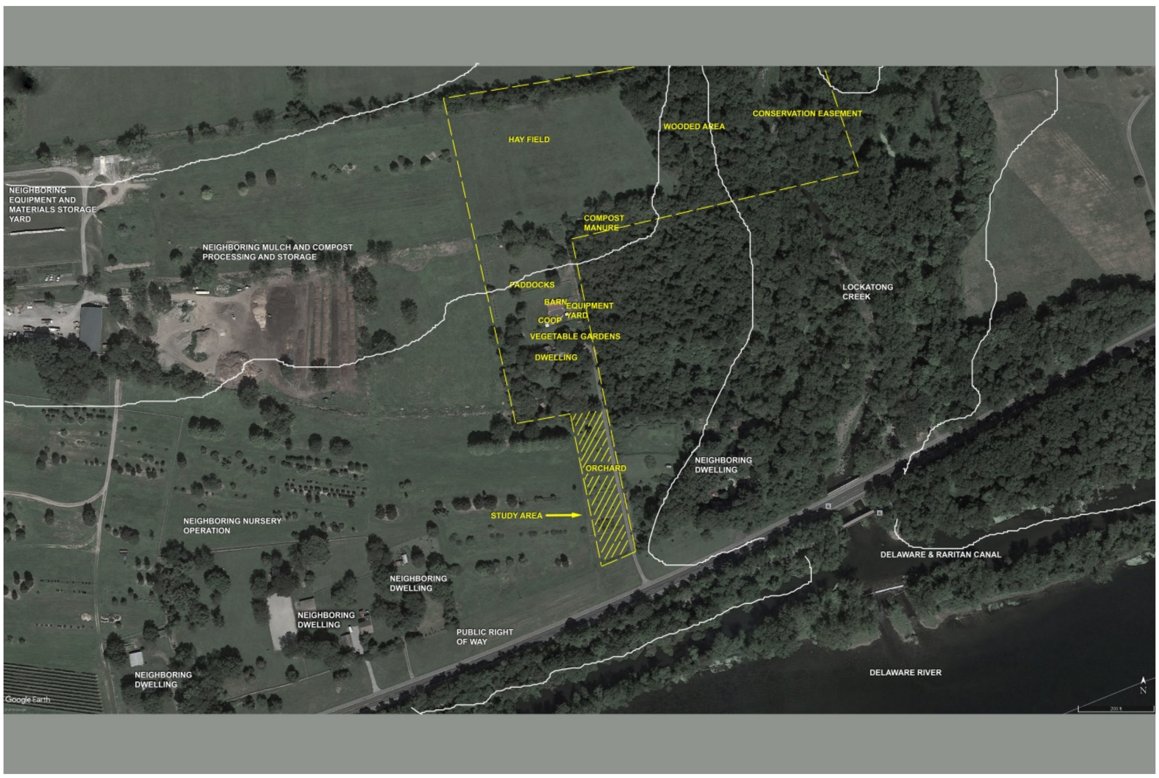


Figure 3: Land Use / Land Cover for Site and Surrounding Area (Base map source: Google Earth, n.d.-b)

INVENTORY AND ANALYSIS

This project aims to design with, rather than in spite of, natural processes in order to create a design that optimizes ecological function, agricultural productivity and aesthetic value. To do this requires an exhaustive inventory of the natural processes, forces, and elements already occurring at the site and in the surrounding area. As Ian McHarg notes, "knowledge of physical and biological processes…is essential to understand nature…as an interacting process that represents a relative value system, and that can be interpreted as proffering opportunities for human use – but also revealing constraints, and even prohibitions to certain of these" (McHarg, 1995, pp. 127–128). This in-depth inventory and subsequent analysis is expected to help eliminate non-viable and inappropriate plant and land use choices and result in a limited, but robust set of design options.

Geology

The site and surrounding area is on the Stockton Formation, the most productive of the unconsolidated aquifers in Hunterdon County (Delaware Township Environmental Commission & Banisch Associates, Inc., 2004, p. 13). Because of poorly yielding formations elsewhere in the township, development pressure is likely to be higher in the southern and western areas of Delaware Township. This is because the Stockton Formation is capable of meeting residential and small-commercial or public water supply needs as well as irrigation demands which may increase to meet changing agricultural needs (Mulhall, 2004, p. 15).

Delaware Township and the study site fall within the Piedmont physiographic province, or the Triassic lowlands. Its shale, sandstone, and argillite formations are less resistant to erosion than the adjacent Highland gneiss rock. The New Jersey Piedmont slopes gradually southeastward from about 400 feet above sea level to sea level at Newark Bay. Although generally flat or gently rolling, waterways have cut steep valleys in parts of the terrain (Collins & Anderson, 1994, p. 39).

Physiography

Understanding the physiography of the site is critical to identifying where microclimates exist and for making better plant choices based on this understanding. In addition, it can help identify where interventions might cause or retard environmental degradation. For example, development, and/or deforestation on steep slopes may create the potential for erosion and sedimentation. For agricultural purposes, landform can suggest where and where not to graze livestock to avoid erosion and contamination, where and how to use of fertilizers and pesticides, and what type of cultivation practices work best on a site. Aesthetically, landform helps guide the development of spaces that people will feel comfortable inhabiting.

The Southern Piedmont is characterized by a series of gently to steeply sloping hills that trend from northeast to southwest. Near the Delaware River, steep to very steep slopes are the result of past erosion. Elevations within the township range from slightly more than 540 feet above mean sea level…to slightly less than 80 feet along the banks of the Delaware River (Mulhall, 2004, p. 3). The Lockatong and Wickecheoke Creeks have formed ravines and are bordered by slopes greater than 25 percent (Delaware Township Environmental Commission & Banisch Associates, Inc., 2004, p. 29)

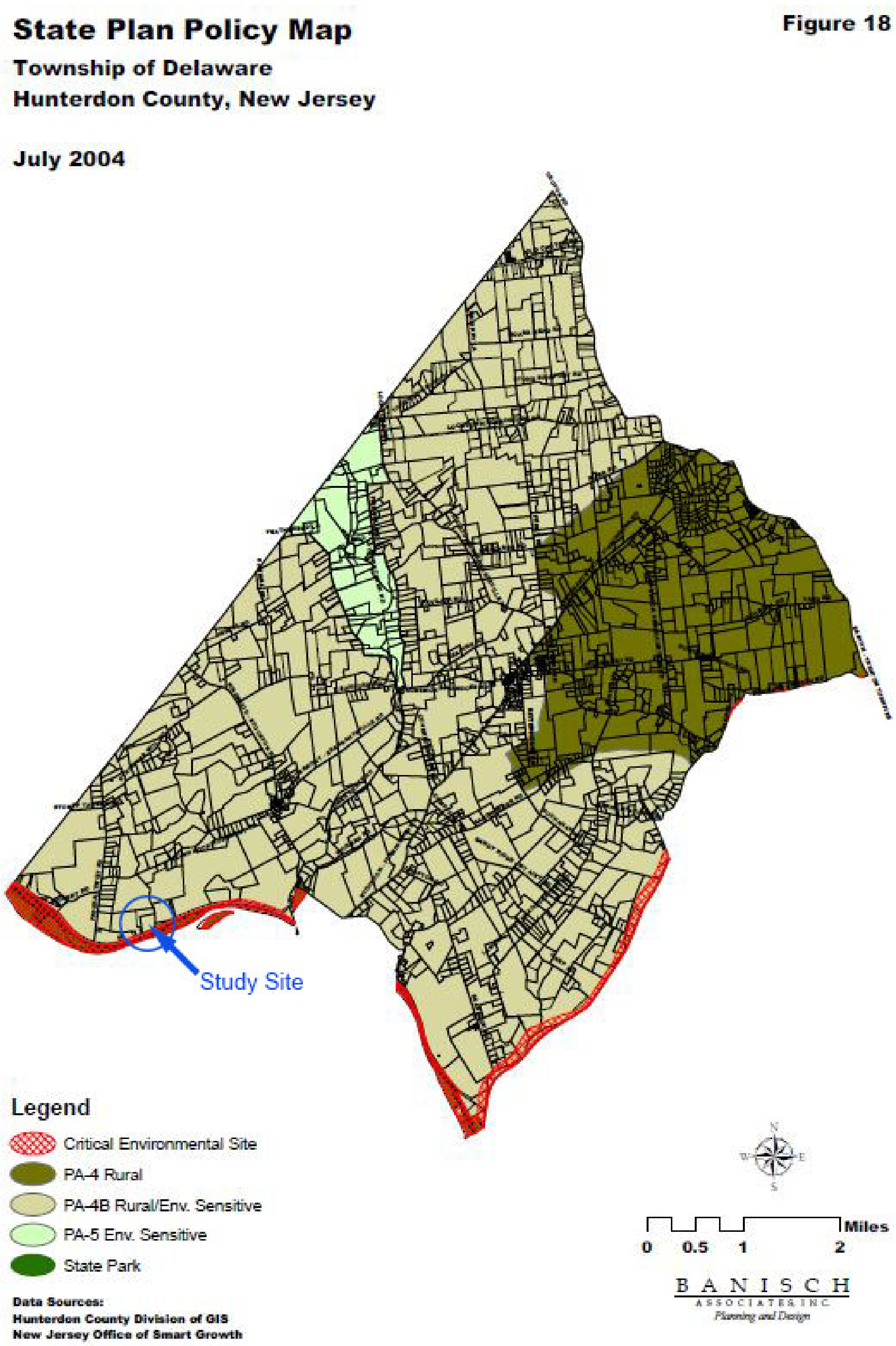


Figure 4. State Plan Designations for Site and Surrounding Area (Delaware Township Environmental Commission & Banisch Associates, Inc., 2004, p. 56)

Areas to the south of the property are classified as wetlands and have been designated a critical environmental site. This designation applies to all Delaware

Township land between Route 29 and the Delaware River and township islands in the Delaware River.

Steep slopes on the west bank of the Lockatong Creek (greater than 25 percent) passing through this and the neighboring property to the east, are considered highly erodible, and are protected by a conservation and drainage easement on the property. A ridgeline to the north and west and varied topography to the south and east of the ridgeline causes precipitation to drain primarily into the Lockatong Creek or to pool in low-lying areas just to the north of Route 29 where the orchard is located. The topography also caused temperature inversions as cold air drains downhill into the river valley.

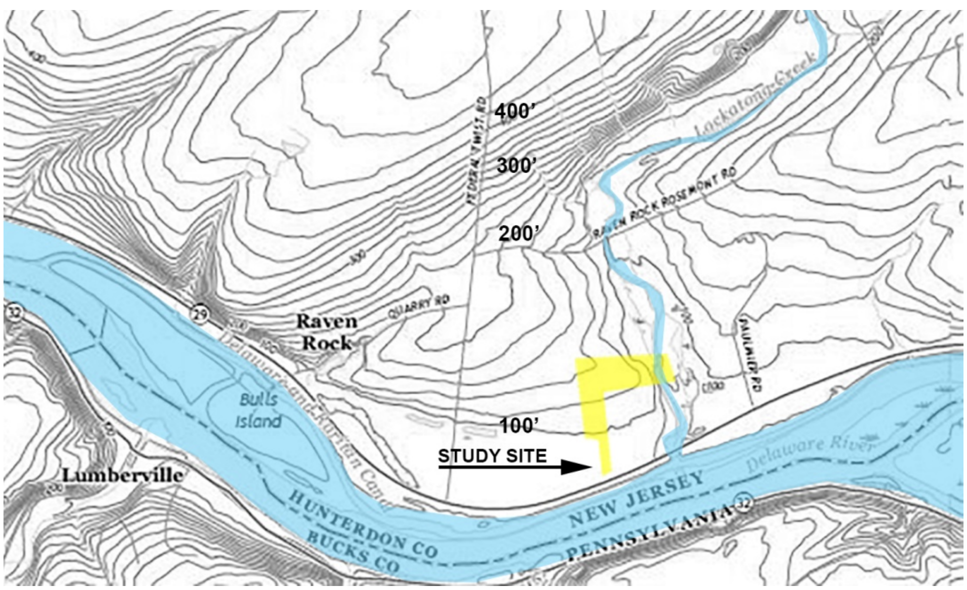


Figure 5: Topography of Area Surrounding Study Site (Base map source: USGS, n.d.)

The topography of the study site is varied and includes a 14-15 percent slope, a drainage area prone to flooding, and relatively flat or gently undulating areas. Its long edges are open to neighboring properties and mostly unprotected by landform or vegetation from wind and floodwaters. The sloping area is somewhat protected by vegetation.

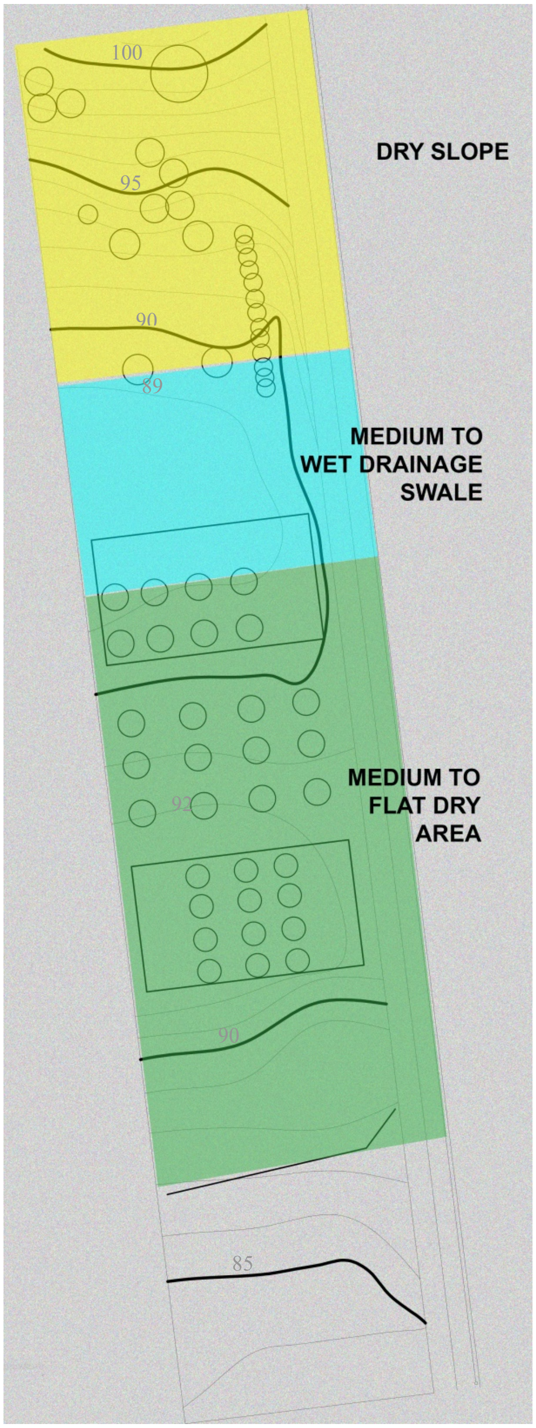


Figure 6: Topography of Study Site

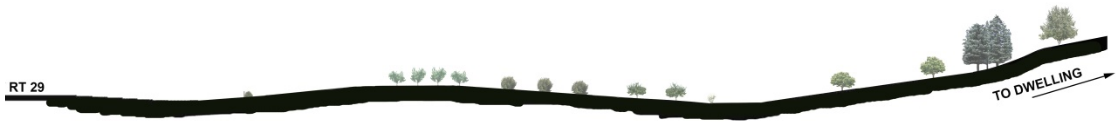


Figure 7: Section View of Study Site

The south facing, sometimes shady, slope on the northern part of the site, tends to be dry, with some shade in the afternoon. The drainage swale is in full sun, but becomes inundated before the rest of the site and stays wet longer. Grasses, forbs and woody plants that tolerate a wide range of moisture and thrive in full sun, would be best for this area. The rest of the flat or gently undulating land does not represent any special conditions based on the topography, but does suggest favorable growing conditions. However, because of the slopes and drainage area, there is potential for erosion as well as run off from fertilizers, pesticides, herbicides, and manure if grazing animals are introduced on the site

Climate

Because this project focuses primarily on the use of plants to meet design goals, a careful study of climatic elements is essential for appropriate plant selection. Elements such as solar aspect, drier south sloping areas, strong winds, fog, frost and temperature inversions, snow drift, and extreme weather events, are key considerations for plant selection.

In Hunterdon County, temperatures vary significantly between summer and winter and exhibit large daily and day-to-day fluctuations as well. These temperature differences are due to the direction of prevailing winds which in the winter, are from the northwest and bring cold air from Canada, and in the summer, from the southwest and bring moist tropical air masses from the Gulf of Mexico (Collins & Anderson, 1994, p.

42). In Delaware Township, temperatures in January average 30.4 degrees Fahrenheit while temperatures in August average 74.1 degrees Fahrenheit. The annual temperature averages 53.0 degrees. The growing season (number of consecutive days on which average temperature is above 43 degrees Fahrenheit) averages 155 days with the average date of the last killing frost being May 4 and the average date of the first killing frost being October 7. However, killing frosts have occurred as early as mid-September and as late as mid-June. Delaware Township is within USDA hardiness zone 6a (Delaware Township Environmental Commission & Banisch Associates, Inc., 2004, p. 4).

Because the site is in a valley that slopes toward the Delaware River, temperature inversions occur frequently and can cause late spring frosts that can damage blossoms and cause fruit set failure. In the summer, morning fog concentrates over the Delaware River and study site and burns off later in the day providing some moisture and protection from summer heat and drought.

Average annual precipitation for the area is 46.59 inches. Over the past 20 years, annual precipitation has ranged from 37.10 inches in 2001 to 72.49 inches in 2011(NOAA National Centers For Environmental Information, 2017). “Measurable precipitation falls on approximately 120 days. Fall months are usually the driest with an average of eight days with measurable precipitation. Other seasons average between 9 and 12 days per month with measurable precipitation”(Office of the State Climatologist, Rutgers University, 2017).

Wind speeds are higher in winter than in summer, with the highest average speed of 13.42 miles per hour occurring in December, January and February and the lowest average speed of 7.8 miles per hour occurring in August. Wind speeds fluctuated from a low daily wind maximum of 9 mph to a high of 38 mph in January 2016. In August of 2016, the daily wind maximum ranged from 10 to 29 mph (NOAA National Centers For Environmental Information, 2017). Because of its long western edge, the site is exposed to nearly constant wind that brings with it windborne seeds, snow and potential pesticide drifts, tree and blossom damage, and the potential to uproot trees particularly in wet soil.

With the exception of the northern slope, the site is in full sun throughout the day. On the summer solstice, the site experiences 15 hours of daylight and on the winter solstice, 9 hours and 18 minutes of daylight. The long western edge exposes the site to the strong afternoon sun.

According to the NOAA National Centers for Environmental Information, average annual temperatures have risen 3 degrees over the past century and higher than normal warming is expected to continue. Heat waves, unpredictable weather, and extreme precipitation events are expected to intensify while cold waves are expected to be less severe (NOAA National Centers For Environmental Information, 2017).

The climatic conditions suggest some directions for both the design of the site as well as for plant selection. Because of the unpredictability of and need to accommodate a late frost, it is important to choose fruit and nut bearing plants that are as late blooming as possible. A windbreak would also help moderate the effect of wind damage on blossoms and plants, would serve to reduce the effects of the strong afternoon sun in the summer, and snow drift in the winter. Even with a tall wind break, plants in the orchard would still receive a significant amount of full sun because of the lack of tall vegetation to the east. The frequency of sleet and glaze and the prediction of increasing frequency of extreme weather events suggest that plants be chosen for hardiness, strength and resilience. Heat waves and droughts, which have occurred in several recent summers, are exacerbated by the site's exposure to sun, again suggesting plants selected for their adaptability to a variety of climatic conditions.

Soil

Soil analysis informs design decisions related to plant selection, grading, water management, structure construction, and other land uses. Appropriate plant selection is essential for enhancing ecological function, agricultural productivity, and aesthetic value. Although plant selection is a function of many environmental factors, soil pH, texture, and drainage are among some of the most important. Potential contamination is also an important consideration, particularly on land used for food production. In addition, ground nesting bees are important crop pollinators and it is helpful to know whether the soil is conducive to their nesting or if other means of attracting these pollinators is necessary.

The soil on the site is well drained flood plain alluvium derived from sandstone and shale. It is described by the Web Soil Survey as 85 percent Pope fine sandy loam, high bottom, 0 to 2 percent slopes, occasionally flooded, and 15 percent minor components. Areas with this type of soil are considered prime farmland. Depth to water table as well as depth to any restrictive layer is greater than six feet (Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, Web Soil Survey, 2017).

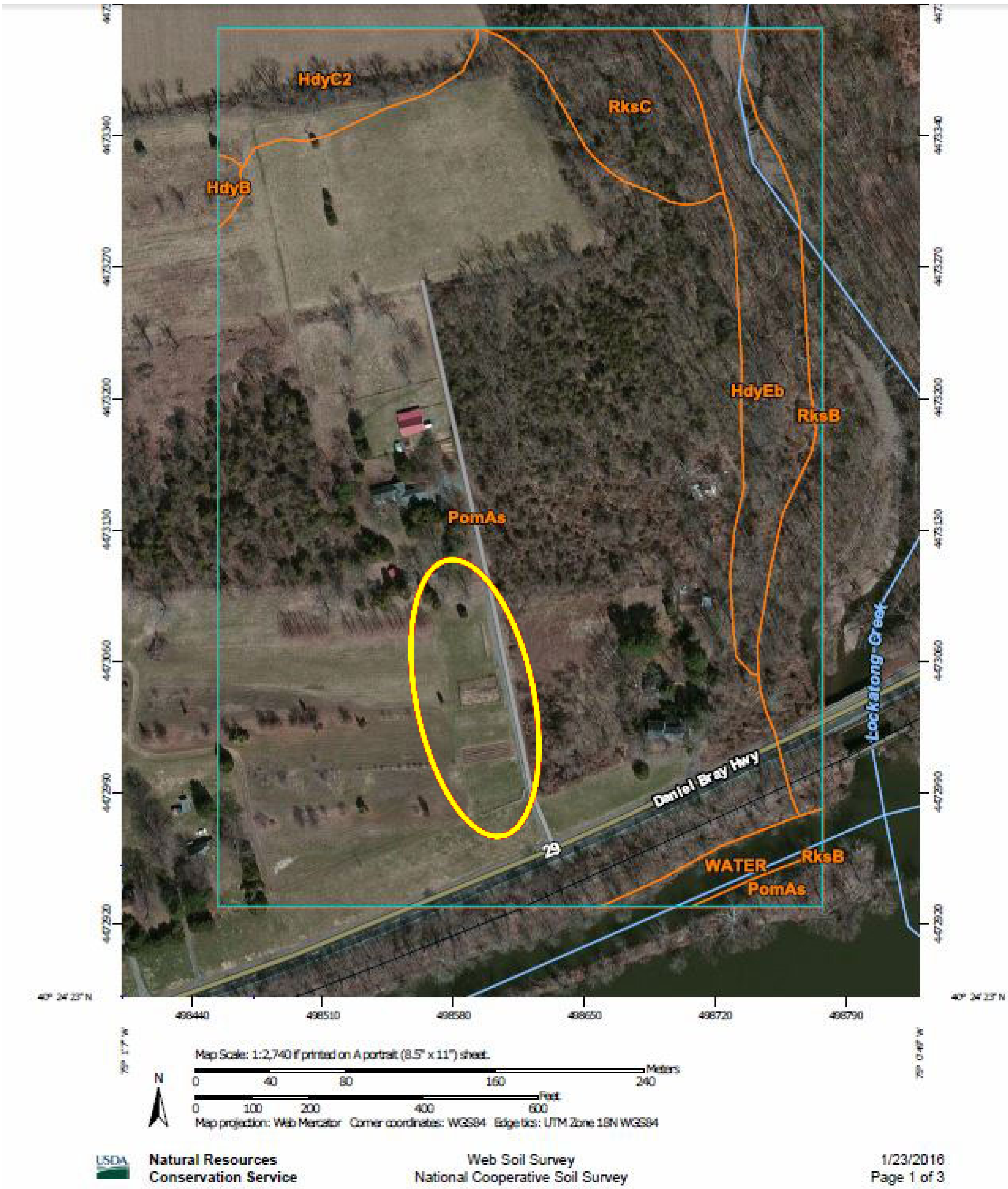


Figure 8. Soil Map of Study Site (Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, Web Soil Survey, 2017)

A soil analysis was conducted in spring 2016 with the help of the New Jersey State Soil Scientist and the Natural Resources Conservation Service. Although in agricultural production, soil borings to a depth of 40 inches, showed no evidence of compaction or plow pan. A soil boring from the gently undulating area between the road and drainage swale on the site showed fine, sandy loam in the A1, A2, Bw1, Bw2 horizons and loamy sand in the C horizon. As expected, a second boring from the drainage swale showed increased silt in the A horizons, loam in the Bw1 horizon and sandy loam below that. Of the four samples taken to test for pH, all showed the soil to be slightly alkaline.

SOIL ANALYSIS								
Horizon	**Depth (cm)**	**Color**	**Texture**	**Structure**	**Friability**	**Roots**	**pH**	**Notes**
Site 1: Higher Elevation, fruit trees								
A1	0 to 9	Dark, yellowish brown (10YR 3/4)	Fine, sandy loam	Moderate fine & medium granular	Friable	Common very fine and fine, few medium	Slightly alkaline (7.6)	
A2	9 to 31	Dark, yellowish brown (10YR 3/4)	Fine, sandy loam	Mod., med. subangular blocky & mod. fine & med. granular	Friable	Few very fine & fine; clear wavy boundary		
Bw1	31 to 45	Dark brown (7.5YR 3/4)	Fine, sandy loam	Mod., med. subangular blocky		Very few fine	Slightly alkaline (7.8)	Slight increase in clay
Bw2	54 to 80	Dark brown (7.5YR 3/4)	Sandy loam/loamy sand	Mod.,med. subangular blocky	Friable			
C	80 to120	Dark brown (7.5YR 3/4)	Loamy sand	Weak, fine subangular blocky	Very friable			
Site 2: Drainage Swale								
A1	0 to 10	Dark, yellowish brown (10YR 4/4)	Silt loam	Mod., fine granular	Friable	Common very fine and fine, few medium	Slightly alkaline (7.6)	Accumulation of silt-sized particles in surface horizons
A2	10 to 30	Dark, yellowish brown (10YR 3/4)	Silt loam	Mod., med., subangular blocky & mod., fine granular	Friable	Common very fine and few fine		1% strong brown (7.5YR 4/6) iron concentrations
Bw1	30 to 58	Dark brown (7.5YR 3/4)	Loam	Mod., med. dubangular blocky		Very few fine	Slightly alkaline (7.4)	
Bw2	58 to 90	Dark brown (7.5YR 3/4)	Sandy loam	Mod. subangular blocky	Friable			
C	90 to 110	Dark brown (7.5YR 4/4)	Sandy loam/loamy sand	Weak mod., subangluar blocky	friable			
Other: Soil is well drained, alluvial sediments. Both borings fit Pope series properties (course-loamy, mixed, active, mesic Fluventic Dystudepts)								
XRF ANALYSIS								
Levels in each horizon of each boring were significantly below remediation standards. (Soil tested for: Ag, As, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Rb, Sb, Se, Sn, Sr, Ti, V, Zn, Zr)								

Table 2. Soil Analysis for Study Site (Shaw, 2016)

In addition, x-ray fluorescence (XRF) analyses were conducted and no soil contamination was found.

Stockton, NJ

Date	Time	Reading	Site	Mode	Ag	As	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Rb	Sb	Se	Sn	Sr	Ti	V	Zn	Zr
4/27/2016	9:56:10	#2C	1	A1	<LOD	<LOD	186	<LOD	<LOD	26	<LOD	11722	<LOD	432	<LOD	11	47.6	<LOD	<LOD	<LOD	26	2389	<LOD	47	439
4/27/2016	9:59:30	#3C	1	A2	<LOD	<LOD	134	<LOD	<LOD	26	<LOD	8628	<LOD	436	<LOD	14	36.6	<LOD	<LOD	<LOD	22	2421	<LOD	31	728
4/27/2016	10:01:19	#4C	1	Bw1	<LOD	<LOD	163	<LOD	<LOD	50	<LOD	12405	<LOD	389	<LOD	11	42.2	<LOD	<LOD	<LOD	31	2361	<LOD	43	512
4/27/2016	10:03:15	#5C	1	Bw2	<LOD	<LOD	174	<LOD	<LOD	40	<LOD	12884	<LOD	351	<LOD	12	51.3	<LOD	<LOD	<LOD	25	1889	<LOD	37	253
4/27/2016	10:05:18	#6C	1	C	<LOD	<LOD	144	<LOD	<LOD	25	<LOD	9783	<LOD	279	<LOD	<LOD	36.5	<LOD	<LOD	<LOD	15	1824	<LOD	30	169
4/27/2016	10:55:52	#7C	2	A1	<LOD	<LOD	243	<LOD	<LOD	54	<LOD	18917	<LOD	822	<LOD	36	61	<LOD	<LOD	<LOD	34	2940	<LOD	75	371
4/27/2016	10:58:34	#8C	2	A2	<LOD	<LOD	284	<LOD	<LOD	56	20	21318	<LOD	996	<LOD	36	68	<LOD	<LOD	<LOD	28	3548	<LOD	75	300
4/27/2016	11:02:28	#9C	2	Bw1	<LOD	<LOD	139	<LOD	<LOD	48	<LOD	19126	<LOD	724	<LOD	16	60	<LOD	<LOD	<LOD	22	2987	<LOD	52	377
4/27/2016	11:04:14	#10C	2	Bw2	<LOD	9	169	<LOD	<LOD	46	<LOD	16359	<LOD	931	<LOD	<LOD	48.4	<LOD	<LOD	<LOD	30	3037	<LOD	44	336
4/27/2016	11:05:32	#11C	2	C	<LOD	<LOD	<LOD	<LOD	<LOD	69	<LOD	11828	<LOD	303	<LOD	<LOD	42	<LOD	<LOD	<LOD	<LOD	972	<LOD	34	238

	Ag	As	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Rb	Sb	Se	Sn	Sr	Ti	V	Zn	Zr
Avg Values, Surface Soils in NJ (Motto, Rutgers U)		7.2	427	0.24	7.1	19.9	15.6			553	20.9	28.6				3.6			48.7	71.3	
Mean Values, Eastern US Soils (USGS, Shacklette and Boerngen, 1984)		7.4	420		9.2	52	22	25000	0.12	640	18	17	53	0.76	0.45	1.5	120	3500	66	52	290
NJ DEP Soil Remediation Std Residential Direct Contact Health Based Criteria	390	19*	16000	78	1600		3100		23	11000	1600	400		31	390				78	23000	
NYS DEC, Soil Cleanup Objectives, Residential Use	36	16**	350**	2.5**		36	270		0.81	2000**	140	400			36					2200	

*The Soil Remediation Standard for Arsenic is based on natural background levels in soil.

**SCOs for As, Ba, Cd, Mn are based on background levels in rural soils.

University of Connecticut soil lead recommendations:

< 100 ppm	No precautions necessary
100 to 400 ppm	Follow BMPs: pH between 6 and 7; add O.M.; avoid leafy greens, herbs, root crops.
>400 ppm	No food crops.

Table 3. Results of NRCS XRF Analysis (Shaw, 2016)

During fall 2017, soil was sampled from ten areas on the site and submitted to the Rutgers Soil Testing Laboratory for analysis. In all cases but one, the soil was found to be slightly acidic. Existing plantings of chestnut, apple, hazelnut and stone fruit (peaches and plums) were deemed appropriate for the soil and relatively minor amounts of fertilizer recommended. The level of organic matter was determined to be high for the northern slope but typical of sandy loam elsewhere on the site.

		Macronutrients				Micronutrients				
	pH	P	K	Mg	Ca	Zn	Cu	Mn	B	Fe
North Slope	6.15	Abv	Opt	Opt	Bel	Adq	Adq	Hi	Low	Hi
Under Chestnuts	6.42	Abv	Abv	Abv	Opt	Adq	Adq	Hi	Adq	Hi
Between Chestnuts	6.33	Abv	Opt	Abv	Opt	Adq	Adq	Hi	Adq	Hi
Drainage Swale	6.03	Abv	Abv	Opt	Opt	Adq	Adq	Hi	Adq	Hi
Under Apples	6.93	Abv	Abv	Abv	Abv	Adq	Adq	Hi	Adq	Hi
Between Apples	6.99	Abv	Opt	Abv	Abv	Adq	Adq	Hi	Adq	Hi
Under Hazelnuts	6.25	Abv	Opt	Opt	Bel	Adq	Adq	Hi	Adq	Hi
Between Hazelnuts	6.16	Abv	Opt	Opt	Bel	Adq	Adq	Hi	Low	Hi
Under PeachPlum	7.07	Abv	Abv	Opt	Abv	Adq	Adq	Hi	Low	Hi
Between PeachPlum	6.86	Abv	Abv	Abv	Abv	Adq	Adq	Hi	Low	Hi

Table 4. Macronutrient and Micronutrient Soil Analysis [Key: Macronutrients shown at above (Abv), at (Opt) or below (Bel) recommended levels. Micronutrient levels are shown as adequate (Adq), high (Hi), and low (Low).]

The deep, fertile, friable soil of floodplain alluvium poses few constraints for plant selection. It supports root growth and optimal drainage and requires minimal amendment. Plant selection will be based on the pH values derived from the later Rutgers Soil Testing Laboratory analysis that was based on a more thorough sampling of the site than the earlier NRCS analysis.

Hydrology

Local hydrology has important implications for decisions regarding land use and agricultural practices. The majority of Delaware Township is in the Central Delaware Watershed which drains into the Delaware River and the Delaware and Raritan Canal, which supplies water to central New Jersey. Of the seven NJDEP designated subwatersheds in Delaware Township, four drain into the D&R Canal and Delaware River including the Lockatong subwatershed (Delaware Township Environmental

Commission & Banisch Associates, Inc., 2004, p. 21) The Lockatong Creek is classified as Category 1 trout maintenance stream (NJ-GeoWeb Map Viewer, 2016). The area around the Lockatong Creek is designated a riparian area and has steep slopes considered highly erodible. A conservation and drainage easement limits activity around the portion of the Lockatong that flows through the study property. The majority of the orchard area and the riparian area around the Lockatong Creek are within the 100 year floodplain (Banisch Associates, Inc., 2004, p. 14, 19).

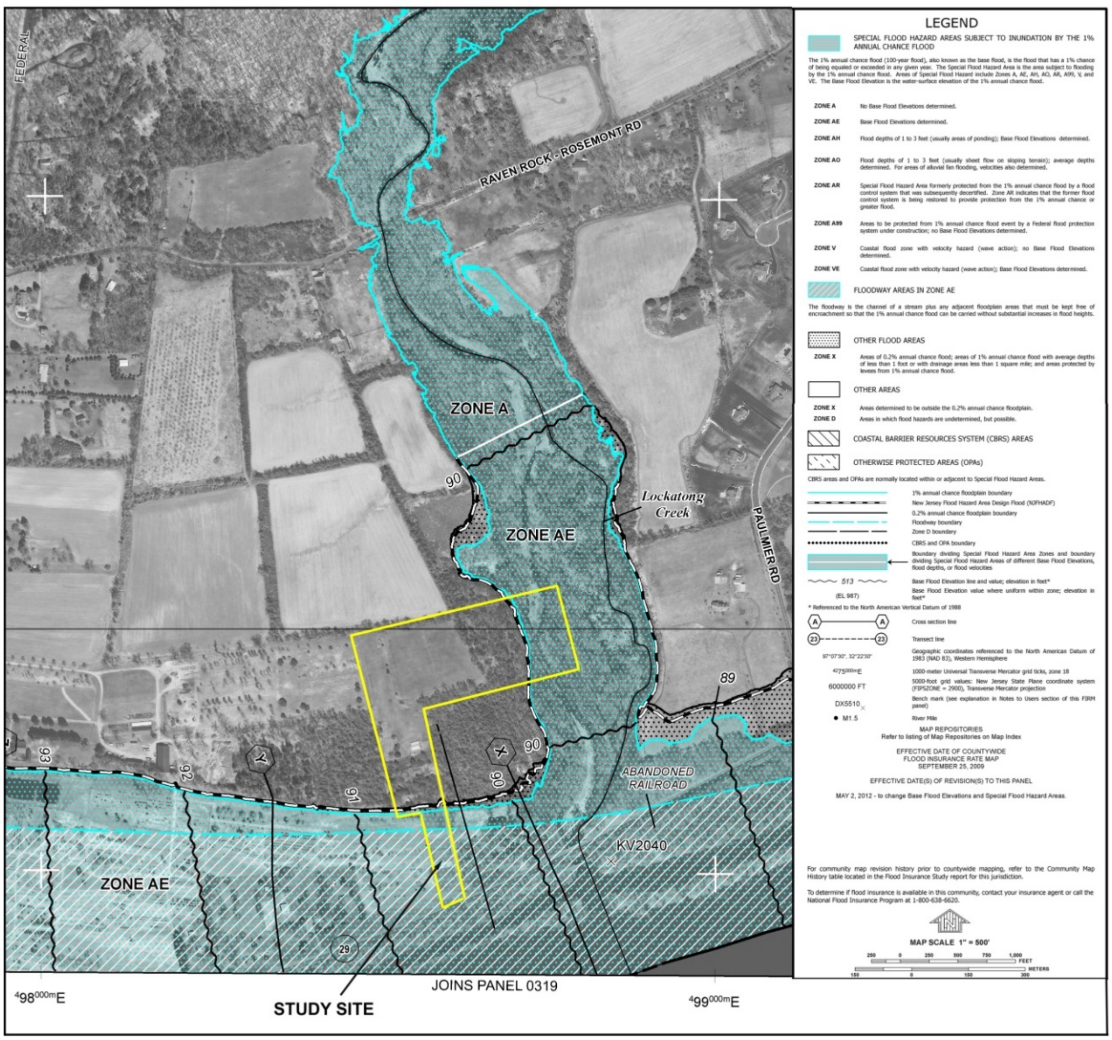


Figure 9: FEMA Map of 100 Year Floodplain and Study Site (Federal Emergency Management Agency, 2012).

According to the Federal Emergency Management Agency (FEMA), the site is within the 100 year flood plain. Flooding has however, happened with greater frequency in recent years, with major flooding from Warren County downstream to Trenton, occurring in September of 2004, April 2005, and June 2006 and causing a total of close to $745 million of damage in the states of New York, New Jersey and Pennsylvania (Army Corps of Engineers, n.d.). Since 2008, at least three major floods have occurred, although they may not have qualified as 100 year floods. Removal of neighboring trees and forest has increased the volume of flood water in the orchard area.

Figure 10. Flooding at the Study Site

Flood waters generally progress from west to east during moderately intense or extended rainfall. When major storms and upstate water releases cause the Delaware

River to exceed its carrying capacity and the Lockatong Creek flow into the surrounding floodplains, the water flows from east to west.

Because of its location on a flood plain, this area is generally not considered suitable for housing and related activities. The *Flood Hazard Area Control Act,* (N.J.S.A. 58:16A-50 et seq. and *Regulations*, N.J.A.C. 7:13-1.1 et seq.) regulates activities in the 100-year floodplain to minimize damage and environmental degradation from flooding and requires stream encroachment permits for construction of structures, placing of permanent fill, or alteration of streams (ANJEC, 2002, p. 23).

Plants in the flood plain must be able to tolerate occasional inundation, which may last up to three days after a storm. However, because the soil is well drained, flood water recedes quickly once a storm event ends or the Delaware River resumes accepting water from its tributaries. Plants that are covered by flood water are generally coated with silt after the water recedes. This suggests a greater use of taller, woody plants where possible.

Flooding can also carry seed and have a significant impact on the type and number of species on the site. In a 1994 experiment, Mitsch and colleagues created two identical kidney-shaped wetlands at the Olentangy River Wetlands Research Park in Columbus, Ohio. One of the wetlands was planted with 2400 propagules of 13 typical wetlands species, the other was left unplanted. Both areas were then continuously flooded with identical amounts of water from the Olentangy River. By the fourth year of the experiment, 58 percent of the unplanted wetland was covered by plants, as was 51 percent of the planted wetland. The total species count of the planted wetland increased from the 13 introduced species to a total of 65 species, the unplanted wetland increased from 0 to 54 species, and forty-nine species were common to both (Mitsch et al., 1998, pp. 1020–1023). The results of this study suggest that efforts to maintain a preferred species mix particularly among groundcover plants in a flood plain may require extra effort.

Vegetation

One of the most important considerations for this site is to understand the existing vegetation as well as the vegetation mostly likely to exist if site maintenance is reduced. In his book on the Lenape, Herbert Kraft describes the likely environment of the Lenape of the area:

> The Indians inhabited a serene and seemingly endless wilderness where the ocean waters and streams were clear, and the air was fresh. Fish, shellfish, and crustaceans abounded in rivers, lakes, and estuaries, while deer, elk, bears, and other mammals, including an occasional mountain lion, flourished in fields and woodlands. Countless passenger pigeons darkened the skies, and ducks, geese, herons, and cranes flocked on lakes and marshes. Weed covered fields and underbrush nurtured turkeys and quail, while eagles and ospreys circled overhead, diving occasionally to pluck fish from the waters (Kraft, 1987, p. xi)

Since then, the natural vegetation New Jersey has been disturbed and displaced by human settlement and development and impacted by introduced flora, fauna, and pathogens. According to Collins and Anderson (Plant Communities of New Jersey), there are three upland forest types in Northern New Jersey: the Mixed Oak forest; the Hemlock-Mixed Hardwood forest; and the Sugar Maple-Mixed Hardwood forest. These forest types are found in mesic habitats on slopes, hilltops, ravines, valley floors and flat land (Collins & Anderson, 1994, p. 87).

The Mixed Oak forest occurs in the Piedmont and is the most likely type to grow in the area of the study site. It is a forest made up of red, white, and black oak and occasionally chestnut and scarlet oak. Other large trees in this community include hickories, red maple, sugar maple, white ash, tulip tree, American beech, black cherry, black birch, sour gum and American elm. The most abundant understory tree is the flowering dogwood, but hop hornbeam, sassafras, and ironwood trees are also common. In the shrub layer are viburnums, spicebush, black huckleberry and witch hazels and vines include poison ivy, Virginia creeper, Japanese honeysuckle, and wild grapes. Early season herbaceous plants include violets, mayflower, and garlic mustard and late summer and fall plants include goldenrod, asters, grasses and ferns (Collins & Anderson, 1994, pp. 109–113).

Similar plants plus introductions and invasives can be observed in both the managed and unmanaged areas of the property. Adjacent to the northern edge of the orchard is a combination of white pine, hemlock, dogwood, maple, oak, black walnut, eastern red cedar, and ornamental plantings. Transects of the unmanaged woodland in the property's conservation and drainage easement area reveal an upper story of ash, eastern red cedar, beech, tulip, and black walnut and an understory of dogwood, multi-flora rose, Russian olive, and a variety of brambles. Wild grape, oriental bittersweet, poison ivy and Japanese honeysuckle make up the vine layer. Spring ephemerals consist mostly of chickweed, garlic mustard and wild garlic.

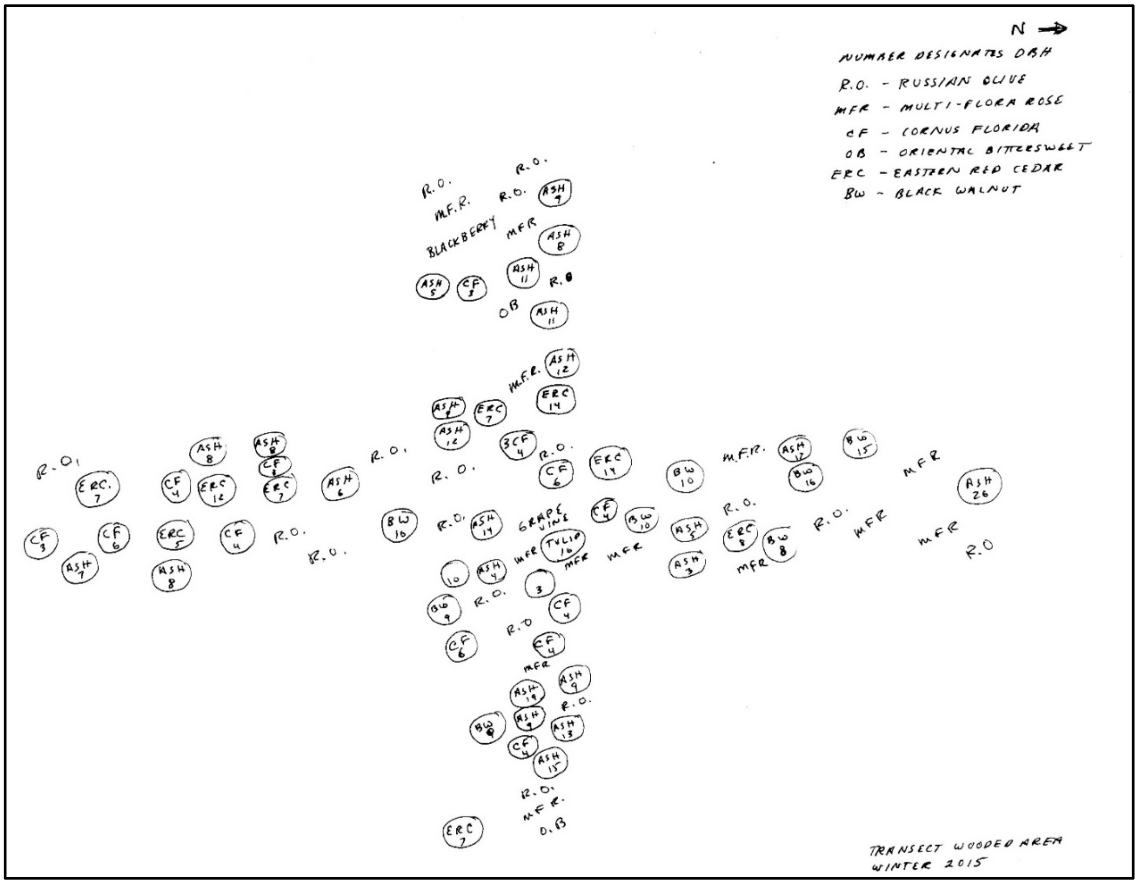


Figure 11: Transect of Wooded Area on Property (Conducted Winter, 2015)

The site is bordered to the west by land used for nursery stock and wine grape production. The land surrounding the nursery stock is mowed several times per year and is made up mostly of grasses and forbs. Occasionally during a growing season, the fields are sprayed with glyphosate, presumably to inhibit the growth of mugwort (*Artemisia vulgaris*) and other invasives. Overspray and drift have not impacted the study site to date. To the east, and separated by gravel drive, is a combination of land occasionally used for vegetable production, areas that are frequently mowed, and wooded areas. Winds and flood waters likely carry seed from neighboring properties to the study site.

The current groundcover is made up of over 30 species of plants. (Please see Appendix A.) The relative number of each species varies by month, with forbs dominating in the late spring and warm season grasses dominating in late summer. White clover, a variety of sorrels, creeping thyme, chickweed, and grass or grass seedlings are relatively profuse, while plantains, wild strawberry, smartweed, and dandelion are found, but in relatively low numbers. The shrub layer is insignificant, with a few introduced Pyracantha shrubs along the split rail fence and butterfly bush in a small ornamental area in the northern area of the orchard. A large silver maple, a small, introduced white pine, and several white firs, flowering dogwoods, and eastern red cedars make up the non-agricultural plants in the orchard area. Several serviceberries were recently introduced in the drainage swale near the apples to attract early season pollinators to the early blooming apple trees.

Over the past eight years, a number of plants have been introduced in an attempt to establish an upper story of fruit and nut bearing trees, including: Chinese chestnut, apple, blight resistant hazelnut, peach and plum trees. All fruit and nut bearing trees were introduced within the last five years. The chestnuts were reasonably productive during the previous two seasons. The hazelnuts produced nuts in 2016, but many shells were empty. Peaches were produced but succumbed to what appeared to be a fungus and did not persist on the tree. No plums were produced. A limited number of berry plants (honey berry, blue berry, and strawberry) have also been introduced. Ornamental plots were originally interspersed among the agricultural plantings although most have been removed. Several aging Concord grape vines are planted along the driveway, produce little, and suffer extensive damage Japanese beetles, birds, and fungus each year.

Typical maintenance of the orchard area includes pruning trees in the winter to reduce canopy density, weekly mowing around trees during the growing season, occasional weed suppression around trees with glyphosate and spraying for fungus and insect pests with an organic fungicide/insecticide. When Japanese beetles threaten tree vigor, non-organic spray is applied. Fertilizers are not applied.

Since all trees have been planted within the last five years, it is difficult to discern whether lack of productivity is a result of immaturity or something else. The apples have been on the site the longest and have proven to be problematic. They often blossom before pollinators are active suggesting the need to either enhance early pollinator populations or to replace the trees with later flowering varieties. Early blossoms have also been destroyed by late frost. In addition, the apples require frequent (at least weekly) applications of organic orchard sprays to produce mature, edible fruit. This suggests replacing them with more productive and pathogen/pest resistant fruit or nut trees. Pollination success seems to vary by year for the chestnut trees and empty hazelnut shells also suggest inadequate pollination. Because hazelnuts are wind pollinated, this suggests the need to intercrop with additional hazelnut plants. The peach and plum trees have grown quickly but also need frequent spraying. Japanese beetles are particularly aggressive with these trees, but are a significant problem for the entire orchard. To enhance ecological function and agricultural productivity, plant selection will need to take into account time of pollination, type of pollinator, resistance to pests and pathogens, and the use of different of additional plants.

Wildlife

Animals both contribute to and detract from the ecology, agricultural productivity and enjoyment of the study site. The most difficult issue related to fauna is that the site is exposed to herbivory by significant populations of deer, rabbits, squirrels and groundhogs. Voles and other small rodents pose a threat as well because of their propensity to gnaw on bark and girdle young trees. Fencing and caging plants represent maintenance obstacles, are not always effective at deterring herbivory, and are aesthetically unappealing and expensive to install.

Common predators can to some extent control herbivores and include domestic and feral cats, hawks and eagles, raccoons, fox, and occasionally coyotes and black bear. Although observed eliminating smaller animal pests, young groundhogs, and occasionally young deer, these predators are generally ineffective in controlling adult deer and groundhog populations. (Human hunters have been relatively ineffective as well.) In addition, groundhogs captured by individuals attempting to rid their properties of the rodents are often released at Bull Island State Park and other nearby locations along the D&R canal. This may account in part for their high numbers in and around the study site.

The bird population includes house sparrows, cardinals, blue birds, chickadees, juncos, woodpeckers, gold finch, catbird, black birds, crows, kingfishers, thrushes, hummingbirds, robins, and occasionally turkeys. There is a significant population of raptors and carrion feeders including bald eagles, a variety of hawks, vultures and owls. Ducks, herons and kingfishers are occasionally observed in and around the Lockatong Creek and Canada geese sometimes frequent the hayfield and orchard areas.

Reptiles and amphibians are occasionally observed. There is a significant toad population and their tendency to burrow has led to significant reduction in tilling. Box turtles are occasionally observed, and on one occasion, a wood turtle was identified. Small garter snakes have also been observed.

Insects

One of the initial metrics of success for this project is enhanced pollination in the orchard area. To date, the experience has been that the fruit trees flower when it is cool in early spring and before many honey bees are active. Previously, the site had a large asparagus patch which was home to large numbers of ground nesting native bees, which are active in cooler and wetter conditions than honey bees (The Xerces Society, 2015, p. 7). This suggests an opportunity to design and plant to increase populations of native bees. The site does however attract a large number of European honey bees later in the season, particularly when white clover is in bloom. This presents an opportunity to introduce agriculturally productive plants that could be pollinated at the same time.

Other common insects include ants that seem to be located primarily in the soil surrounding the apple trees. The site also attracts large populations of Japanese beetle and tent caterpillars that have caused excessive damage to the fruit trees and vines. Further investigation into Integrated Pest Management techniques may hold some promise.

Experiential Qualities

Views differ dramatically depending on location. At the northern slope, dawn redwoods to the west and mixed hardwoods and conifers to the north and east of the study site provide a prospect/refuge feel. The view is of the whole orchard, the driveway, part of an open field with nursery stock to the west, and part of the partially unmanaged, partially mown neighboring property to the east. Deteriorating split rail fences mark the southern and eastern boundaries. Beyond the southern fence line is a mown right of way, the road, and the wooded D&R Canal bike path that blocks views of the Delaware River. Although sounds from the road and the bike path are prominent because of the acoustics of the river valley, the experience from the northern slope is pleasant and one that invites lingering and observing.

Once the down the slope, the road is no longer visible, but more each of the neighboring properties comes into view – more open field and nursery stock to the west and more of the mix of kept-up and unkempt to the east. The space feels more expansive, but hidden from the road. There is a sense of exposure because of the proximity of the neighboring properties and the flat, openness of the flood plain. It can be a warm, sunny, peaceful place to work or it can be a windy, hot or disturbing place to be depending on the surrounding activities. The closer one gets to the road, the less comfortable and inviting the space.

Approaching from Route 29, which is at this part designated as a Scenic Byway, can be jarring. Turning into the site, the 400 – 500 foot driveway sets up the approach to the dwelling. The view to the northwest has been degraded by deforestation and a large and highly unsightly equipment, vehicle, mulch, and compost storage yard on the neighboring property. The deteriorating fence line on the site and shabby Pyracanthas planted along it do little to block or improve the view. A hedgerow of invasive vines to the east of the drive also degrades the approach.

The site itself is designed in a typical agricultural grid and is somewhat appealing during the growing season depending on the level of defoliation by insects. When mowed and managed it looks well kept, but visually bleeds into the nursery property to the west.

A visual buffer along the long western edge and at the southern fence line would go a long way toward enhancing the views and comfort of the site. Replacement of the fence and invasive vines to the east of the driveway with some type of low growing hedge would help define the site in a more appealing way. Within the agricultural area, the grid could be broken up to create a more interesting and appealing space with intentional paths created for foot traffic and equipment access.

GROUNDCOVER EXPERIMENT

Because enhanced agricultural productivity is a goal for the site, a two year experiment beginning May 2015 was conducted to determine if pollination could be enhanced with ground cover and if the ground cover could effectively compete against other less desirable ground covers. Legumes were chosen for their ability to fix nitrogen and to potentially be a source of nitrogen depending on mowing/tilling regimens. Perennial clovers were chosen to avoid the need to reseed and for ongoing establishment and weed suppression potential. The three clovers used were chosen for their relatively low or semi-prostrate growth habit and appropriateness to New Jersey climate. All seeds were sourced from OutsidePride.com and arrived inoculated.

In mid- May, 2015, 36 test plot areas measuring approximately 9’ x 9’, each surrounding an introduced fruit or nut tree, were sprayed with herbicide (glyphosate). While much of the vegetation exposed to the herbicide was eliminated, the emergence of new plants required that the plots be resprayed several weeks later. New plants emerged again about two weeks after the second herbicide application, so the plots were lightly tilled, the debris removed, and the test plots sown by hand in mid-June 2015, with Red Clover (*Trifolium pretense),* White Dutch Clover (*Trifolium repens)*, and Birdsfoot Trefoil (*Lotus corniculatus*). Because of the limited number of test plots, the type of clover was not randomly assigned in order to ensure replication in as many microclimates/locations as possible. The plantings were established during the 2015 growing season and plots were mowed once in August.

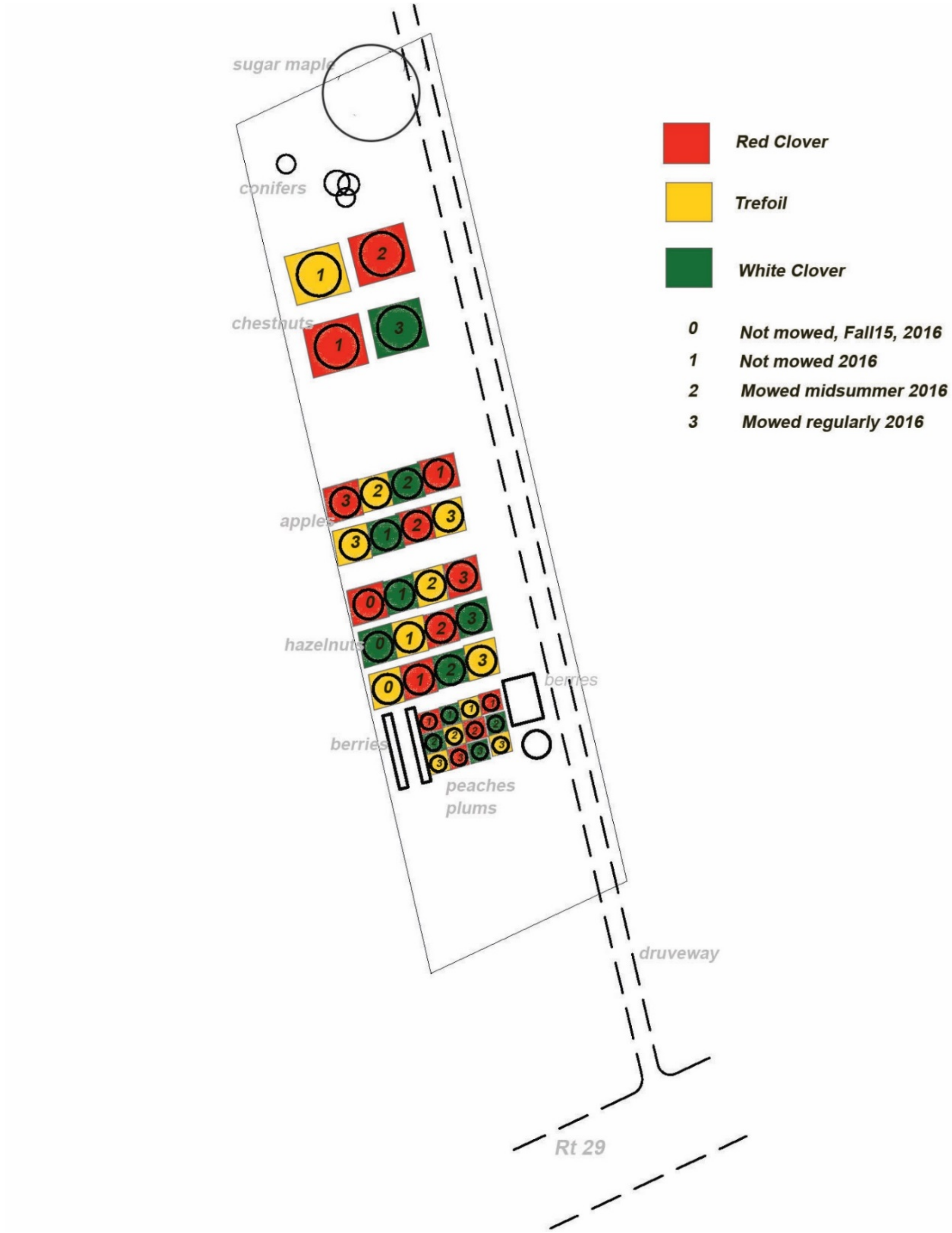


Figure 12. Mowing Regimen for Study Site

Methods

During the 2016 growing season, various mowing regimens were conducted on the test plots to determine the effect on all three clovers. Three plots were not mowed from August, 2015, through all of 2016. Eleven plots were mowed in the fall of 2015, but not during 2016; 11 were mowed in the fall of 2015 and mid-summer 2016, and 11 were mowed in the fall of 2015 and regularly during the 2016 growing season. Because of the limited number of test plots, mowing regimens were not randomly assigned in order to ensure that all possible combinations of clover and mowing regimens would be equally replicated. Stems counts were conducted in mid-June on randomly selected 50cm x 50cm areas within each test plot and again in mid-August on these previously selected areas. The number and types of species were also identified along a transect the length of each plot.

Stem count data for *Trifolium pretense, Trifolium repens*, and *Lotus corniculatus* were analyzed to determine if stem counts were affected by initial seeding regimen, mowing schedule, and month when counts were conducted (June and August.) Community indices – total stem count, species richness and the Shannon Diversity Index – were also analyzed relative to initial seeding regimen, mowing schedule, and month.

To account for the variation within the data sets the General Linear Model with negative binomial regression using R Statistical software (R Core Team, 2016) was used. Coefficients for the General Linear Model are in logit units, (i.e., the logarithm of the odds that one variable will affect another). Species richness represents the number of species in a given environment and diversity was measured using the Shannon Index of general diversity which accounts for both the number of each species present in a given environment and how close the count of each species is within that environment (Odum, 1971, p. 144).

Results

Stem counts revealed that the existing groundcover in the orchard area included over 30 species of plants. (Please see Appendix A.) Of those, fewer than ten species made up the majority of plants in both counts, although the species that made up the majority of plants varied between the June and August counts. In absolute numbers, *Trifolium repens* far outnumbered *Trifolium pretense* and *Lotus corniculatus* on the site, with stem counts for June at 7,196, 906, and 192 respectively, and stem counts for August at 1,514, 95, and 294 respectively.

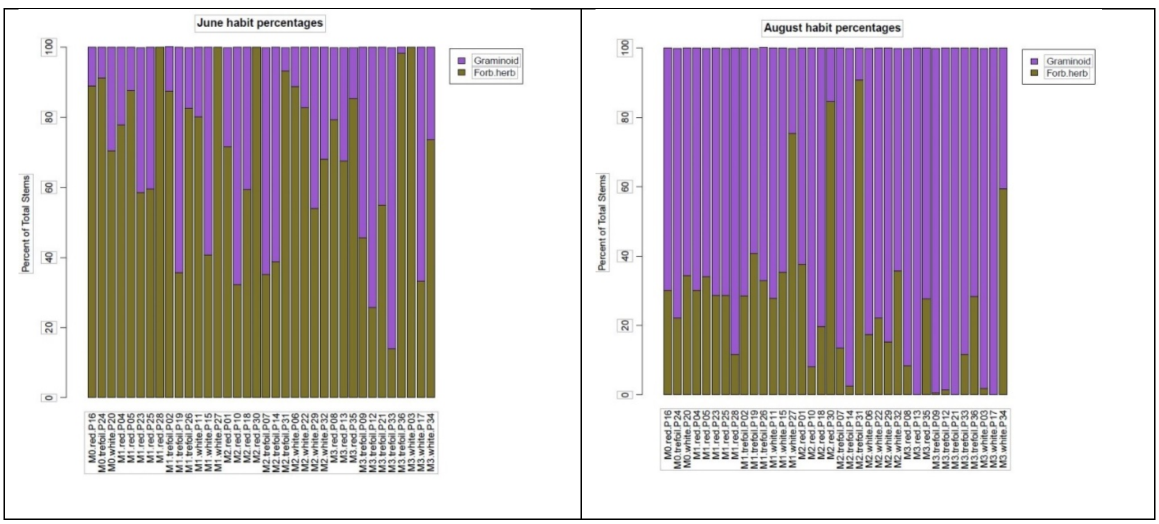


Figure 13: Percentage of Forbs and Graminoids in Early and Late Summer (Salisbury, 2016a).

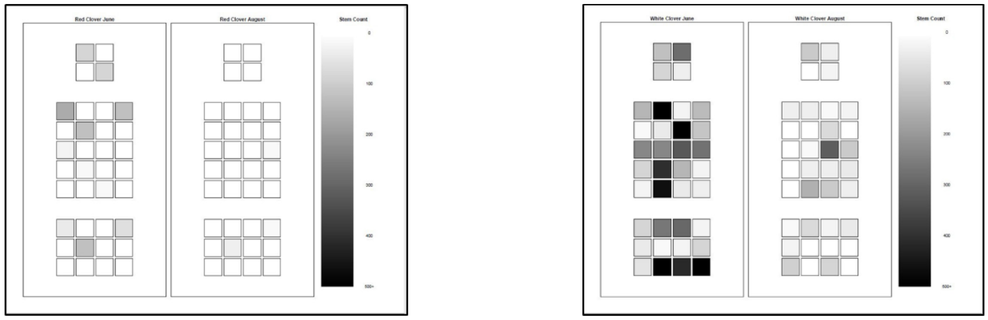


Figure 14: Counts of *Trifolium pretense* and *Trifolium repens* in Early and Late Summer (Salisbury, 2016b)

While total stem count tended to be higher in June than August, the difference was not statistically significant. Month of count did not appear to affect diversity. Species richness was significantly higher in June than in August.

The effect of initial seeding was determined based on combined data from the June and August stem counts. Initial seeding influenced the amounts of *Trifolium pretense* and *Lotus corniculatus*, with *Trifolium pretense* showing the highest stems counts in plots seeded with *Trifolium pretense* and *Lotus corniculatus* showing the highest stem counts in plots seeded with *Lotus corniculatus*. Seeding treatment did not affect *Trifolium repens* stem counts which were high in each plot regardless of initial seed type, reflecting the impact of the regional species pool. When the effect of the month of the count was considered, the initial seed type and measurement month both affected *Trifolium pretense* counts which were lower in August. *Trifolium repens* counts, which were also lower in August, were only affected by the measurement month. *Lotus corniculatus* was not affected by either measurement month or initial seeding.

Plots initially seeded with *Lotus corniculatus*, tended to have higher total stem counts and plots seeded with *Trifolium pretense* tended to have higher diversity, although not significantly so. Initial seeding also had no significant effect on total stem counts, richness and diversity when analyzed for June and August separately.

Mowing had very little effect on the stem counts of all three clovers when measurement month data were combined. However, when June and August counts were analyzed separately, the counts of *Trifolium pretense* and *Trifolium repens* were significantly lower in August in the plots that were not mowed during the 2016 growing season, but there was no interaction between mowing and month. *Lotus corniculatus* stem counts did not vary significantly between June and August.

When the mowing regimens were analyzed for combined June and August stem counts, counts were significantly higher in regularly mowed plots than in plots that were not mowed. While diversity trended down with increased mowing, neither diversity nor richness was significantly affected by mowing regimen.

When the June and August counts were analyzed separately, total stem counts tended to increase with mowing frequency in both June and August, but not significantly so. Species richness and diversity were more affected by mowing regimen in August than in June, and there was a significant interaction between regular mowing and the month of August resulting in a reduction of species richness.

There was little interaction between mowing regimens and initial seed type. *Trifolium pretense* stem counts in plots initially seeded with *Trifolium pretense* were significantly affected by seeding, but not by mowing. *Trifolium repens* stem counts in plots initially seeded with *Trifolium repens*, were likewise affected. *Lotus corniculatus* was significantly affected by mowing regime, producing greater counts when not mowed in *Lotus corniculatus* plots and when mowed mid-summer *Trifolium pretense* in plots.

Discussion

Findings from the clover experiment provide some guidance for site maintenance and groundcover planting decisions. Mowing seems to have an effect, although not always a statistically significant effect, on abundance, richness and diversity. For example, stem counts were higher in regularly mowed plots when data from June and August combined. When June and August data were not combined, total stem counts increased with mowing frequency, but not significantly. Species richness was higher in June than in August, and regular mowing was shown to significantly reduce richness in August. There were no statistically significant changes in diversity, but diversity did appear to trend down with mowing. This suggests that a program of limited mowing might support a greater number of plant species.

Trifolium repens already existed on the site in large numbers, and although it showed a precipitous decline in the August count, there were still nearly four times as many as the other two clovers combined. During the spring and early summer it spreads throughout the site and its low growth habit allows the flower heads to remain when the site was mowed. Honey and bumble bees were most frequently observed on the flowers.

Establishing a substantial number of *Trifolium pretense* would most likely require frequent initial seeding and like *Trifolium repens* its numbers would decline significantly by late summer. When protected from herbivory, it grew to a height of 12-18" and the flower head attracted pollinators. It is likely that it would be more successful than *Trifolium repens* as a pollinator attractor in a meadow where its height would be an advantageous.

Lotus corniculatus would also be likely to require repeated seeding to become established. While it seemed to struggle to grow, where it wasn't mowed it was able to establish a fairly healthy patch and held its flowers later in summer than the other clovers. Its height and growth habit may make it a viable choice if a meadow was established, but there is some question of its ability to compete effectively.

All of the clovers bloomed after the apples, peaches and plums bloomed and so did not function as pollinator attractors. *Trifolium pretense* did however, attract deer and groundhogs which is not a sought after function. Because of *Trifolium repens* spreading habit, it may be most useful for outcompeting weeds in the early summer, but because of its late summer decline, does not compete well against warm season grasses. Additional investigation would be needed to identify early pollinator attractors and beneficial warm season plants.

SUMMARY MATRIX OF INVENTORY AND ANALYSIS

Findings	**Implications**
Land use history • Originally Eastern Deciduous Forest • Area likely either forested or in agricultural production since the 1600's • Site in agricultural production since at least 1930 • More, smaller, specialty farms in the area	Land has been disturbed for hundreds of years, but regenerated forest when abandoned. Suggests an opportunity to design a novel ecology that leverages natural processes that support a more forested eco-agricultural system.
Character of area • Located on New Jersey and National Scenic Byway • Located on section of Delaware River designated as Wild and Scenic	A naturalistic design would be most in keeping with the character of the area.
Land use / land cover of township, 1986 to 2007 • 11% decrease in acres in agriculture • No change in forest • 50% increase in urban	Suggests development pressure, but this is not likely to be an issue for the site specifically since development is highly restricted in township floodplains.
Township population • More than doubled since 1930 • 2010 Census: 4,563 • Little change predicted between 2010 and 2015	Increased residential population represents a larger local market for agricultural products, particularly specialty products.
Zoning •	
Geology • All township water sourced from bedrock aquifers • Site and surrounding area located on the Stockton Formation – the most productive aquifer in the county	Increases development pressure on area surrounding site. Water availability can be an issue if plants chosen require irrigation.

Physiology • Site located south and downhill of a ridgeline that follows the course of the Delaware River on the New Jersey side • Ridge is cut by the Lockatong Creek to the east • Site is long and narrow with a sloping section, a drainage swale, and gently undulating land that abuts Rt. 29	Varied landform creates microclimates which must be taken into account when making plant selections.
Climate • Strong west winds • Strong, late afternoon sun • Full sun from drainage swale to road • Temperature inversions create unpredictable and late spring and early fall frosts • Potentially damaging sleet and glaze • Extreme weather events more frequent	Wind dispersed seed and long edges increase the challenges of maintaining a specific plant mix in the groundcover. Winds and sun can be drying during hot weather. Later blooming, more resilient plants are more likely to succeed and be productive. Strong winds may be helpful for wind pollinated plants such as chestnut and hazelnut.
Soil • Deep, fertile, well drained • Fine, sandy loam • Slightly acidic	Poses few limitations for plant selection.
Hydrology • Site is in a floodplain • Inundation can last several days	Seed dispersal from flood waters increases the challenge of managing the plant mix in the groundcover. Plants on the site must be able to tolerate at least three days of inundation and an influx of silt.
Vegetation • Groundcover made up of 30 plus species • Existing vegetation typical of area, including *Juniperus virginiana* (vector for cedar apple rust)	Plant choices should be appropriate to the Eastern Deciduous Forest of the area and temperate riparian zone of the site. Plant selection and potential removal should

• Poor level of pollination of introduced fruit and nut trees	also take into consideration pathogens and pests.
Wildlife • Herbivory a problem because of excess deer and groundhogs	Fencing, guard animals and appropriate plants select should all be considered.
Insects Beneficial insects include honey and bumble bees • Ground nesting bees no longer appear to inhabit the site • Japanese beetles and tent caterpillars cause excessive damage to fruit and nut trees	Planting to encourage beneficial insects and deter pests should be considered.
Experiential qualities • View to west, particularly on approach is extremely unsightly • Site does not provide any place to rest or linger	Visual buffers to block the view to the west and spaces designed to make the site more habitable would enhance the appeal of the site.
Groundcover experiment • Clovers selected for experiment yield to warm season grasses in late summer • Taller varieties subject to herbivory and/or are not competitive • Low growing variety flowers profusely and attracts pollinators, but later than fruit trees bloom.	Further evaluation into plant selection in the groundcover layer should consider how to include earlier blooming forbs and create a manageable meadow given seed dispersion by wind and water dispersion from adjacent land.

CASE STUDIES AND DESIGN APPROACHES FOR ENHANCING BIODIVERSITY

Additional investigation was done to develop a planting strategy that would not only enhance ecological function but would also enhance agricultural productivity. The following case studies represent different approaches to integrating principles of ecological design into agricultural production.

Muir Glen Organic Tomatoes, Colusa County, California

Based on research showing a strong link between buzz pollination by bumble bees and increased tomato yields, Muir Glen Organic Tomatoes partnered with the Xerces Society to establish a mile long native plant hedgerow along a barren, compacted dirt roadside in an area where massive monoculture farms and attendant farming practices had reduced biodiversity to a minimum. After terracing the roadside slope to provide a level planting area and stabilizing the soil, the team planted large, drought tolerant plants on the top of the slope and drip irrigated for two years until the large shrubs became established. A diverse understory of native wildflowers was then direct seeded along the lower part of the slope to further stabilize the soil and increase plant diversity. Monitoring by University of California-Davis scientists showed that after only the first year, nearly twice as many bees were found at the Muir Glen site as were found on nearby farm fields without hedgerows. Additional research by scientists at University of California-Berkeley showed that benefits include not only increased pollination, but reduced crop damage due to an increase in beneficial insects that prey on crop pests (The Xerces Society, 2015, p. 10)

Figure 15: Muir Glen Organic Tomatoes Hedgerow being planted (The Xerces Society, 2015, p. 11).

Figure 16: Muir Glen Organic Tomatoes Hedgerow after establishment (The Xerces Society, 2015, p. 15).

NelsonBrydWoltz Conservation Agriculture Studio

Oakencroft Farm (2008 – 2009) is a project of Nelson Byrd Woltz (NBW) Landscape Architects' Conservation Agriculture Studio. The master plan for the 262-acre farm sought to "balance livestock production, vineyards, and production gardens with new goals of improving water quality and biodiversity"(Nelson Byrd Woltz, 2017). Like many of NBW's Conservation Agriculture Studio projects, the first step of the design process was a "bio-blitz" (Biological Baseline Survey), an intensive site inventory approach used to gather information about the ecology of the site. This will be repeated after several years to monitor ecological health. The design goal for the site was to balance agricultural production with ecological conservation by integrating rotational livestock grazing, vegetable production, viticulture, habitat and forest restoration, wetland construction, and the family homestead into a sustainable working farm.

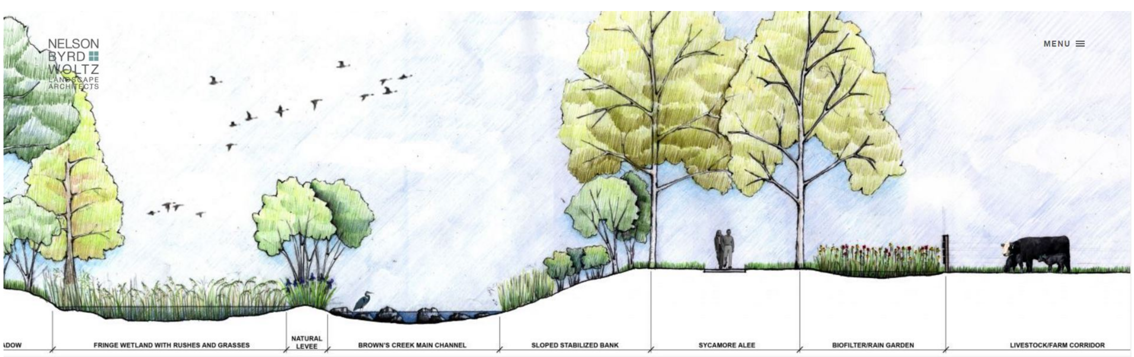


Figure 17: NBW / Oakencroft Farm, Charlottesville, Virginia (Nelson Byrd Woltz, 2017).

In another project, NBW created inviting spaces within ecological agricultural sites. At Medlock Ames, Alexander Valley, California, NBW identified ecological communities and created management plans to enhance their health within the larger site that included 75 acres of vineyards and vegetable production. They were also tasked with designing a tasting room and garden area that would help promote the ideas of conservation, ecological health, and sustainable farming practices while connecting the site and its ecology to the larger region surrounding the farm.

Figure 18: NBW / Medlock Ames, Alexander Valley, California (Nelson Byrd Woltz, 2017).

When NBW owner, Thomas Woltz, redesigns farms, “his chief aim isn’t to pretty them up. Looks matter, but in his broader, more scientific view of aesthetics, beauty springs from the ecological health of the land” (Ward, 2013, p. 100).

New Forest Farm, Viola, Wisconsin

Mark and Jen Shepard founded their 106-acre perennial farm in 1994. The site includes trees, shrubs, vines, canes, perennials, and fungi planted in associations to produce food for humans and animals, fuel, medicines, and visual appeal. Originally a row-crop grain farm, it is now a perennial agricultural ecosystem which uses the oak savannah, successional brushland, and eastern woodlands as ecological models.

In his book *Restoration Agriculture*, Mark Shepard recommends using perennial plant species with a wide range of light tolerance. This includes tall trees that rise above the canopy, canopy trees, understory trees, shrubs, forest floor perennials and vines. He also suggests the use of rotational grazing for weed control and the creation of habitat for insectivores for pest control. Successful imitation of nature requires an understanding of the biome where the farm is to be established and its implications for appropriate plant communities. The farm should then mimic the biome in its vertical structure, spatial distribution, and species mix made up of cultivated substitutes (Shepard, 2013, pp. 66–75).

Figure 19: New Forest Farm, Viola, Wisconsin (Shepard, 2013, p. 251)

Enhancing Diversity of Beneficial Insects, Xerces Society

For agricultural production, beneficial native insects include pollinators as well as predatory and parasitic insects. Basic habitat requirements for these insects are fairly similar; an abundance of flowers – especially native wild flowers – that attract prey and provide nectar and pollen from spring through fall; undisturbed areas for shelter and hibernation; host plants or undisturbed nesting areas for reproduction; and, an environment free of pesticides. To enhance food resources and corridors for movement, insectary plantings, native plant field borders, hedgerows, flowering cover crops, pollinator meadows, butterfly gardens and buffer strips can be installed. Using reduced or no-till practices reduces disturbance, and planting windbreaks and shelterbelts can reduce pesticide and snow drifts. Of the pollinators, which include bees and wasps, flies, butterflies and moths, and beetles, bees are considered most important, because only bees deliberately gather pollen to feed their brood. In some cases, native bees have been found to be more effective pollinators than honey bees, foraging earlier and later in the day and during cold, wet conditions that honey bees avoid. (The Xerces Society, 2011, 2014)

When designing habitats for pollinators, it is important to meet certain conditions. A site should have good sun exposure for warmth and be open to the sky for purposes of navigation. In smaller areas, research suggests that groups of individual plant species should be at least three feet in diameter. Nesting and foraging areas should be close to each other with flowers no more than a few hundred feet from potential nesting areas. Nesting areas can be enhanced by allowing for some bare ground, leaving dead trees standing, building piles of brush or fieldstones, or providing bee blocks and other easily constructed structures. When establishing pollinator habitat, it is recommended that at least three native plants should be in bloom during the spring, summer and fall seasons. Very early spring flowering is important to emerging bees; early to mid-spring flowering for reproduction, and late season flowering for successful hibernation. Plants with different flower sizes, shapes, colors, heights, and growth habits should be included to enhance pollinator diversity on a site and at least one native low growing, warm season bunch grass or sedge should be included to provide nesting sites for bumble bees. Plants treated with systemic insecticides should be avoided when sourcing plants and mowing, grazing or other disturbances related to weed management should be restricted to one-third or one-quarter of the site in a single season (The Xerces Society, 2011)

SUMMARY MATRIX OF BEST PRACTICES

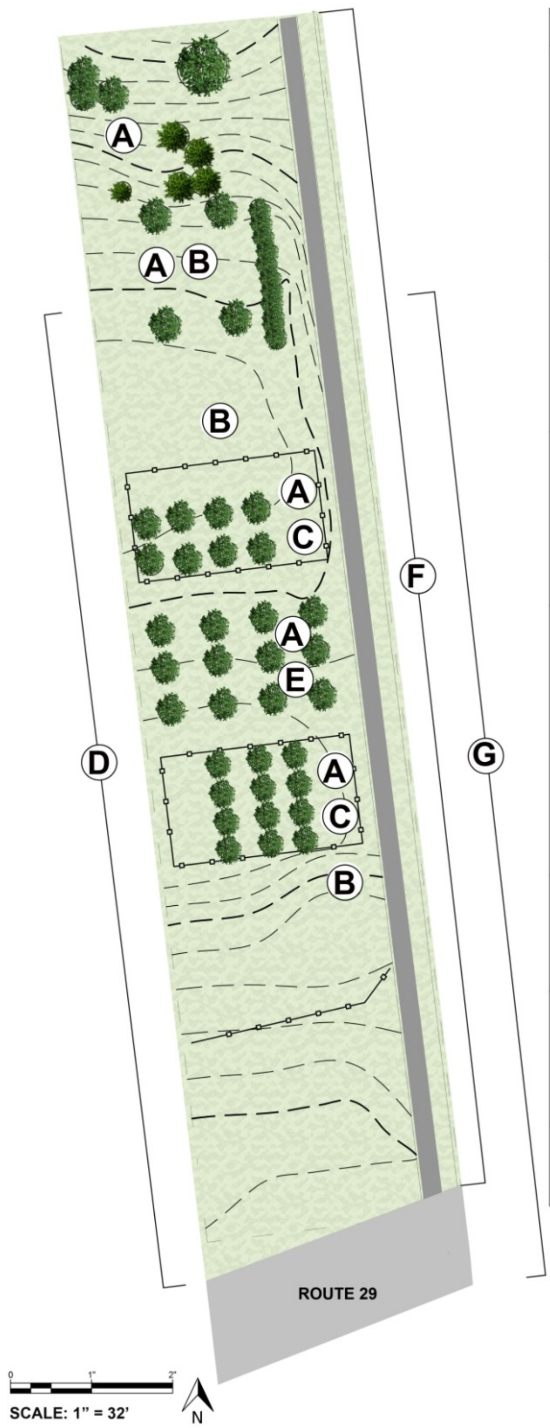
Best practices for enhancing ecological function	**Application to site**
• Match site design and plant selection to appropriate regional and local biome / conditions.	• Site should be planted to match the Eastern Deciduous Forest biome. • Choose plants appropriate to the dry steep slope, wet drainage swale, and average soil moisture areas. • Establish conditions that attract early emerging native bees. • Possibly replace early blooming plants with plants that bloom later to avoid fruit set failure during late frosts due to temperature inversions on the site. • Plant wind pollinated species close together to enhance pollination.
• Replicate appropriate vertical structure, spatial distribution, and species mix to take advantage of resource niches.	• Succession to be stopped at shrubland transitioning to woodland. Open grassland meadows will be maintained. Introduced windbreaks, hedgerows, and fruit trees to provide vertical structure, additional niches, and more varied habitat.
• Remove invasive species to allow establishment of appropriate plants.	• Remove and replace existing hedgerow consisting of oriental bittersweet, Russian olive, Japanese honeysuckle, and multi-flora rose.
• Maintain open, sunny areas to provide warmth and enable navigation for pollinators.	• Largest possible meadow area to be maintained with appropriate plantings.
• Use diverse flowering species that flower together and sequentially in spring, summer, fall.	• Create pollinator meadows with at least three different flowering plants per season and per soil moisture zone.

• Plant at least three species that flower in each season. • Select plants with different flower sizes, shapes, colors, heights and growth habits. • Planted communities should resemble naturally occurring native plant communities. • Include low growing, warm-season, native bunch grass or sedge. • Limit cool season grasses which can out-compete forbs.	
• Group single species of flowers in clumps of at least three feet in diameter to make them easier for pollinators to locate and to reduce energy needed to forage from plant to plant	• Cluster plants or plant in drifts on the site.
• Provide nesting areas with appropriate plants and structures within a few hundred feet of foraging area.	• Locate nesting areas in warm, south facing slope above flood zone. • Construct nesting structures. Leave bare ground on south facing slope for ground nesting bees, maintain bunch grasses for bumble bees, construct and install brush piles, nest boxes or stem bundles for tunnel-nesting bees.
• Create a pesticide free environment. • Eliminate pesticide use. • Use fine needle conifers as a buffer to reduce pesticide drift from neighboring properties. • Avoid sourcing plants from suppliers that treat plants with systemic insecticides.	• Western hedgerow to include Eastern Red Cedar (*Juniperus virginiana*) and sufficient understory to impede drift from neighboring commercial nursery.
• Limit disturbance; plan weed management to maintain diversity.	• Reduce or eliminate tilling by planting perennial crops

• Avoid removing all flowers when mowing • Avoid heavy grazing and use rotational grazing • Mow patches instead of entire site • Use a flushing bar; cut at slow speeds • Cut at a height of 12-16 inches	• Manage weeds on a rotational basis on site to maintain a reservoir of insect and floral diversity • Install perimeter fencing to exclude herbivores.
• Provide a clean source of water	• Provide a source of puddled drinking water
• Link habitat patches; enhance landscape surrounding agricultural area	• Develop long-term plan for entire property that enhances ecological functions and agricultural productivity.
• Gather detailed information about the ecology of the site and monitor over time to determine effectiveness of interventions.	• Develop metrics to gauge ecological function and agricultural productivity (e.g., number and timing of pollinators; fruit set)
Best practices for enhanced agricultural productivity	
• Establish conditions to attract pollinators earlier and more often to ensure enhanced fruit production.	• Increase number and diversity of pollinators, especially native bees, and other beneficial insects to control agricultural pests by providing habitat and forage.
• Use flowering cover crops	• Maintain White Clover (*trifolium repens*).
• Use alternatives to pesticides	• Manage site to attract more predatory and parasitic insects. • Consider using other forms of biocontrol (integrated pest management, augmentative biocontrol).

DESIGN APPROACH AND PROPOSAL

As noted previously, the existing site presents a number of challenges.



	CHALLENGES
A	• LIMITED SHRUB AND UPPER STORY DIVERSITY • LIMITED AGRICULTURAL PRODUCTIVITY
B	• TOPOGRAPHY CREATES MICROCLIMATES WHICH CAUSE DIFFERENT SOIL MOISTURE ZONES • TOPOGRAPHY CAUSES TEMPERATURE INVERSIONS, UNPREDICABLY LATE FROSTS AND FRUIT SET FAILURE
C	• POLLINATOR / BLOOM TIME MISMATCH
D	• WESTERN EDGE - STRONG WEST WIND RESULTS IN BLOSSOM AND TREE DAMAGE, SEED, PESTICIDE AND SNOW DRIFT - STRONG, DRYING AFTERNOON SUN STRESSES PLANTS AND INCREASES WATER USAGE • VIEWS / FEEL OF SITE - UNSIGHTLY VIEW ON APPROACH - PROXIMITY TO ROAD - UNCOMFORTABLY OPEN FEEL
E	• WIND POLLINATED NUT TREES NOT GETTING POLLINATED, EVEN WITH STRONG WINDS
F	• WEEDS AND HERBIVORY
G	• FLOODING

Figure 20: Challenges Associated with the Study Site

In order to address these challenges the following changes are proposed for the site: To enhance upper story diversity and agricultural productivity, several hedgerows will be created using native conifers and fruiting understory trees and shrubs. On the western and southern edges, the upper story of the hedgerow will be made up of Eastern Red Cedar (*Juniperus virginiana*) which will serve a number of functions. As a fine needle conifer, Eastern Red Cedar will function to screen pesticide drift on the windward side of the site. In combination with a fruiting deciduous understory, the diverse hedgerow will provide forage, shelter from strong winds and late afternoon sun, a more enclosed feel to the site, and will screen unsightly views to the west. The east side of the western hedgerow will also be planted in a curvilinear pattern to increase edge effects and boundary habitat. On the eastern property line, the hedgerow will be made up of relatively lower growing species such as *Rhus aromatic* and *Rosa Carolina* to avoid overhead wires and blocking morning sun.

HEDGEROW AND EDIBLES (ARRANGED BY HEIGHT)														
HEDGEROW														
BOTANICAL NAME	**COMMON NAME**	**SIZE**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
JUNIPERUS VIRGINIANA	EASTERN RED CEDAR	30-65												
HAMEMALIS VIRGINIANA	WITCHAZEL	15-20												
ILEX VERTICULATA	WINTERBERRY	3-12												
MYRICA PENSYLVANICA	BAYBERRY	5-10												
ROSA CAROLINA	CAROLINA ROSE	3-6												
HEDGEROW EDIBLE														
BOTANICAL NAME	**COMMON NAME**	**SIZE**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
AMELANCHIER SPP	JUNEBERRY	25-30												
ACTINIDIA ARGUTE	HARDY KIWI	25-30												
ASIMONA TRILOBA	PAWPAW	15-30												
LINDERA BENZOIN	SPICEBUSH	6-12												
ARONIA SPP.	CHOKEBERRY	6-10												
HELIANTHUS TUBEROSA	JERUSALEM ARTICHOKE	6-10												
ARALIA CORDATA	UDO	6-8												
SAMBUCUS CANADENSIS	BLACK ELDERBERRY	5-12												
APIOS AMERICANA	GROUNDNUT	3-18												

Table 5: Plant Selections for Hedgerows with Bloom Times and Colors

Since the topography of the site creates several different soil moisture zones, floristically diverse meadow areas will be created for each zone based on bloom time, diversity of color, and height and include the following mixes:

MEADOW MIX FOR DRY TO MEDIUM SOIL (ARRANGED BY HEIGHT)														
BOTANICAL NAME	COMMON NAME	SIZE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ANDROPOGON GERARDII 4-6'	BIG BLUE STEM	4-6'												
ERYNGIUM YUCCIFOLIUM 4-5	RATTLESNAKE MASTER	4-5'												
HELIOPSIS HELIANTHOIDES	SMOOTH OXEYE	3-6'												
SORGHASTRUM NUTANS	INDIAN GRASS	3-5												
PEROVSKIA ATRIPLICIFOLIA	RUSSIAN SAGE	3-5'												
BAPTISIA AUSTRALIs	BLUE FALSE INDIGO	3-4												
PYCNANTHEMUM INCANUM	HOARY MOUNTAIN MINT	3												
ECHINACEA PURPUREA	PURPLE CONE FLOWER	2-5'												
BAPTISIA ALBA	WHITE FALSE INDIGO	2-4'												
MONARDA FISTULOSA	WILD BERGAMOT	2-4'												
SCHIZACHYRIUM SCOPAR.	LITTLE BLUESTEM	2-4												
SPOROBOLUS HETEROLEPIS	PRAIRIE DROPSEED	2-3												
ANDROPOGON VIRGINICU	BROOM SEDGE	2-3'												
SOLIDAGO SPECIOSA	GOLDENROD	2-3'												
BAPTISIA TINCTORIA	YELLOW WILD INDIGO	2-3'												
GAILLARDIA SPP	BLANKET FLOWER	2-3												
PYCNANTHEMUM TENUIFOLIUM	NARROW LEAF MOUNT MINT	2-3'												
NEPETA CATARIA	CATNIP	2-3'												
NEPETA SPP.	CATMINT	2-2.5'												
SYMPHYOTRICHUM CORDI.	HEART LEAF ASTER	1-5												
SOLIDAGO CAESIA	GOLDENROD	1-3.5'												
SOLIDAGO FLEXICAULIS	GOLDENROD	1-3.5'												
ZIZIA AUREA	GOLDEN ALEXANDER	1-2.5'												
ASCLEPSIA TUBEROSA	BUTTERFLY WEED	1.2.5'												
EURYBIA DIVARICATE	WHITE WOOD ASTER	1.2.5'												
DICENTRA EXIMIA	WILD BLEEDING HEART	1-2'												
MONARDA PUNCTATA	DOTTED MINT	1.5-2'												
COREOPSIS LANCEOLATE	LANCELEAF COREOPSIS	1-2'												
PURPLE LOVE GRASS	ERAGROSTIS SPECTABILIS	1-2'												

Table 6: Plant Selections for Dry Slope with Bloom Times and Colors

MEADOW MIX FOR MEDIUM MOISTURE SOIL (ARRANGED BY HEIGHT)														
BOTANICAL NAME	COMMON NAME	SIZE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SCROPHULARIA MARILAND.	FIGWORT	5-10'												
EUTROCHIUM PURPUREUM	JOE PYE WEED	5-7'												
EUPATORIUM PERFOLIATUM	BONESET	4-6'												
SOLIDAGO CANADENSIS	GOLDENROD	4-5'												
SYMPHYOTRICUM SPP.	NE / NY ASTER	3-6'												
PENSTEMON DIGITALIS	BEARDTONGUE	3-5'												
LIATRIS SPICATA	BLAZING STAR	2-4'												
RUDBECKIA SPP.		2-3'												
PHLOX MACULATA	MEADOW PHLOX	2-3'												
AGASTACHE	GIANT PURPLE HYSSOP	2-2.5'												
PENSTEMON LAEVIGATUS	BEARDTONGUE	1-3.5'												
PYCNAN. MUTICUM	SHORT-TOOTHED MTN. MINT	1-3'												
TRIFOLIUM PRATENSE	RED CLOVER	1-3'												
PHLOX DIVARICATE	WILD BLUE PHLOX	1.5'												
SISYRINCHIUM ANGUSTIFOL.	BLUE EYED GRASS	1-2'												
GERANIUM MACULATUM	WILD GERANIUM	1-2'												
TRIFOLIUM REPENS	WHITE CLOVER	0.5'												

Table 7: Plant Selections for Medium Soil Moisture with Bloom Times and Colors

MEADOW MIX FOR MEDIUM TO WET SOIL (ARRANGED BY HEIGHT)														
BOTANICAL NAME	COMMON NAME	SIZE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
VERONICASTRUM VIRGINIC.	CULVER'S ROOT	4-7'												
PANICUM VIRGATUM	SWITCH GRASS	3-6'												
VERBENA HASTATA	BLUE VERVAIN	2-6'												
LOBELIA CARDINALIS	CARDINAL FLOWER	2-4'												
MONARDA DIDYMA	BEE BALM	2-4'												
HIBISCUS MOSCHEUTOS	HARDY HIBISCUS	2-3'												
LOBELIA SIPHILITICA	BLUE CARDINAL FLOWER	2-3'												
ANEMONE CANADENSIS	CANADA ANEMOME	1-2'												
HYDROPHYLLUM VIRGINIAN.	VA WATERLEAF	1-2'												

Table 8: Plant Selections for Wet Soil with Bloom Times and Colors.

The topography of the site and surrounding area also creates temperature inversions which can cause late frosts which damage blossoms and interfere with fruit set. Cold temperatures late in the spring can also reduce the number of pollinators visiting during bloom time which can also interfere with fruit set. Two approaches will be pursued to address these issues. Because native bees emerge earlier and pollinate during colder, wetter weather than honey bees, native bee habitat and forage will be enhanced to attract bees earlier in the season. This includes providing forage with meadow and understory plantings, brush and rock piles and constructed structures for nesting, and eliminating pesticide use and blocking drift. If attracting early pollinators does not improve fruit set, later blooming fruit tree varieties will be explored as replacements for trees currently on the site. In addition, native fruiting understory trees will be incorporated into the western hedgerow to enhance food production. Maintaining habitat for native pollinators also requires that disturbance be limited. This includes no-till practices and limited rotational mowing and weed management. Further, to reduce disturbance and damage to pollinator forage from herbivory, perimeter fencing would need to be installed. To address these issues, the following design solution is proposed:

Figure 21: Existing Conditions and Proposed Design for Study Site

The proposed plan is likely to invite more human participation in the site by giving it a more sheltered feel, more visual interest from increased floral and faunal diversity, and distinct pathways that make the site access easier. Given the site's location on a national and state scenic byway, it is also hoped that the site will be aesthetically pleasing enough to attract attention to ecological design and possibly motivate others to consider incorporating elements of it into their own small farms.

Figure 22: Southward Perspective of Study Site

CONCLUSION

Ecological design of agriculture holds promise for enhancing biodiversity, connecting wild fragments, effectively producing food for human consumption and creating spaces that are inviting and engaging. Case studies have shown that ecological interventions can be limited to marginal areas associated with farms such as field and road barriers and hedgerows, and as simple as maintaining snags for pollinator shelter or as complex as mimicking a regional biome using agriculturally productive plants to design an entire farm.

There are several key elements common to most ecological design efforts for farms. The most obvious is a need for clear and prioritized goals for the site ecology, agriculture, and human participants. This will help determine what data are collected during the inventory and analysis stage, which design elements are critical to success, and what data collection and maintenance protocols will be useful after a design is implemented. A rigorous inventory and analysis of existing conditions will provide the necessary understanding of the current ecology of the site and of what can, and cannot be, changed on the site. Understanding how the site fits into the regional and local biome helps support workable design solutions as does being explicit about the stage of succession to be replicated. It is also essential to accept that the design solution is not a static one, but rather one that takes a commitment to management, monitoring, and a willingness to reevaluate goals and approaches.

It is hoped that by leading by example, owners of other small farms will be interested in considering an ecological approach to agriculture. it is also hoped that the process developed by this research can be scaled and applied throughout the region.

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APPENDIX A

Plant Species in Stem Count

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Acalypha virginica Virginia Copperleaf	N. Am.	Summer annual	Seeds germinate in late spring when soil warms	Disturbance adapted colonizer of bare ground;	Wide range of moisture, nutrient and light conditions; unmaintained areas (Tredici & Pickett, 2010, p. 210)
Allium vineale Wild garlic	Europe Western Asia N. Africa	Herba-ceous perennial, 1-3’	Aerial bulblets and underground bulblets, rarely from seed; plants grow rapidly in early spring / summer, flower in May/June, then senesce (Uva, Neal, & DiTomaso, 1997, p. 30)	Disturbance adapted colonizer of bare ground	Tolerates wide range of habitats; best in sun or shade in nutrient rich soil (Tredici & Pickett, 2010, p. 302)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Ambrosia artemisiifolia Common Ragweed	North Am.	Summer annual up to 4’	Seeds germinate readily in late spring on bare ground once temp is consistently above 50 degrees	Disturbance-adapted species; tolerant of compacted soil; food for wildlife, esp. birds	Grows equally well in dry, sandy soil and heavy moist soils with a neutral or higher pH (Tredici & Pickett, 2010, p. 130)
Anthemis cotula Mayweed Chamomile			Seed; late summer, early autumn, early spring		Rich, gravelly soil (Uva et al., 1997, p. 112)
Chenopodium album Common Lambsquarters	Europe	Summer annual; up to 6’ tall	Seeds germinate in early summer; dispersed by ground-feeding birds; buried seeds remain viable for years	Tolerant of compacted soil; soil building on degraded land; food and habitat for wildlife; phytoremediation	Best in rich soil; tolerates range of conditions; common in disturbed sites (Tredici & Pickett, 2010, p. 203)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Conyza canadensis Horseweed	North America	winter or summer annual; up to 6' tall	wind dispersed seeds; can germinate on a wide range of disturbed sites	disturbance-adapted colonizer of bare ground	dry, exposed sites in full sun; minimally maintained landscapes; (Tredici & Pickett, 2010, p. 144)
Cyperus esculentus Yellow Nutsedge,	Europe Asia North Am.	Herbaceous perennial; up to 2'	Seeds germinate on moist bare soil; rhizomes from established plants; only tubers winter over	Disturbance adapted colonizer; food for wildlife	Prefers sunny, moist, nutrient rich soil (Tredici & Pickett, 2010, p. 296) Weed of most agricultural, horticultural, and nursery crops; most common on well drained sandy soils or damp to wet sites (Uva et al., 1997, p. 26)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Daucus carota Wild Carrot	Eurasia / N. Africa	Herbaceous biennial	Germinates readily on disturbed sunny sites in spring	Disturbance adapted colonizer of bare ground; food for wildlife	Tolerates full sun and dry soil (Tredici & Pickett, 2010, p. 122)
Digitaria sanguinalis / ischaemum Large/smooth Crabgrass	Europe	Summer annual	Seeds germinate late spring and early summer and remain viable in soil for several years	Disturbance adapted colonizer of bare ground;	Tolerates contaminated or compacted soil; drought tolerant (Tredici & Pickett, 2010, p. 312)
Elytrigia repens Quackgrass	Eurasia N. Am.	Evergreen perennial	Seed, rhizome	Disturbance adapted colonizer of bare ground;	Prefers good soil and full sun; tolerates road salt, compacted soil; (Tredici & Pickett, 2010, p. 316)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Erechtites hieracifolia American burnweed	eastern North America	summer annual; up to 6' tall	wind dispersed seeds; seeds can germinate after years of burial if a disturbance brings seeds to the surface	disturbance-adapted colonizer of bare ground	full sun; grows well on recently burned land; small pavement openings; margins of walls and chain-link fences; in minimally maintained landscape plantings; along railroad tracks (Tredici & Pickett, 2010, p. 146)
Fragaria virginiana Wild Strawberry		Low-trailing perennial	Seeds, spreads by creeping stolons; seed dispersal by birds and animals		Weed of low maintenance turf grass; gravelly, well-drained soil (Uva et al., 1997, p. 296)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Galinsoga ciliata Hairy Galinsoga	Central Am.	Summer annual; up to 2’	Seeds germinate throughout the summer on disturbed soil; a single plant can produce 3 generations in one summer	Disturbance adapted colonizer of bare ground	Full sun, fertile soil (Tredici & Pickett, 2010, p. 150)
Lepidium campestre Field Pepperweed	N. Am.	Winter or summer annual; up to 2’	Seeds germinate fall or spring	Disturbance adapted colonizer of bare ground;	Sunny, compacted soil(Tredici & Pickett, 2010, p. 188) Orchards, nurseries and reduced tillage ag fields (Uva 176)
Lolium multiflorum Annual Ryegrass			Seed		Weed of grain, turf, nursery and other cool-season or perennial crops; most soil types (Uva et al., 1997, p. 58)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Lotus corniculatus Birdsfoot Trefoil	Eurasia	Herbaceous perennial; up to 6” [taller in test plots]	Seeds germinate in early spring; established plants produce new shoots from a perennial crown; stolons and rhizomes develop in fall	Erosion control; soil building	Ability to fix N allows it to grow in nutrient poor sandy soil and full sun; tolerates mowing and drought (Tredici & Pickett, 2010, p. 218)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Microstegium vimineum Japanese stiltgrass	Asia		by seed and vegetative spread by rooting at joints along the stem	Nurse crop for oak; Also eco-threat	full sun to deep shade. It readily invades disturbed shaded areas, like floodplains that are prone to natural scouring, and areas subject to mowing, tilling and other soil-disturbing activities including white-tailed deer traffic (National Park Service, U.S. Department of the Interior, 2017)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Muhlenbergia schreberi Nimbleweed	N. Am.	Herbaceous perennial; up to 2’	Germinates from seed; roots at horizontal nodes	Disturbance adapted colonizer of bare ground;	Wide range of moisture and light conditions; tolerates compaction; mowing encourages its spread (Tredici & Pickett, 2010, p. 322) Does not tolerate cultivation (Uva et al., 1997, p. 62)
Oenothera biennis Evening Primrose	North America	Herba-ceous perennial; up to 6’	Seeds germinate readily in wide variety of disturbed sites	Disturbance adapted colonizer of bare ground	Best on dry, sandy, gravelly soil in full sun (Tredici & Pickett, 2010, p. 242)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Oxalis stricta Yellow Woodsorrel,	Europe and North America	Summer annual; up to 18”	Germinates readily in moist, nutrient-rich soil; capable of germinating from seed buried for a long while; also spreads by rhizome	Disturbance adapted colonizer of bare ground	Best in sun/moist/rich, but tolerates shade and drought (Tredici & Pickett, 2010, p. 244)
Poa annua Annual Bluegrass	Europe	Annual; up to 1’	Seeds germinate in late summer, early fall or spring depending on weather and location; clumps enlarge by aggressive tillering;	Disturbance adapted colonizer of bare ground	Compacted soil (Tredici & Pickett, 2010, p. 332) Best in cool, moist, rich conditions; excess irrigation and fertilization encourage growth (Uva et al., 1997, p. 78)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Plantago lanceolate English Plantain	Europe	Perennial, up to 18”	Dispersal by animals; can sprout from root pieces left in ground	Disturbance adapted colonizer of bare ground	Best in sun and tolerates compacted, pH-neutral soils and close mowing
Plantage major Broadleaf Plantain	Europe	Semi-evergreen perennial	Seeds germinate readily in wide variety of conditions	Disturbance adapted colonizer of bare ground	Best in moist, nutrient rich soil; tolerant of compacted dry soils and close mowing
Polygonum pensylvanicum Smartweed/Ladythumb	North America/ Europe	Summer annual	Seeds germinate in spring	Excellent wildlife food; especially water fowl	Adapted to soils of all drainage classes except drought soils; commonly occurs on mudflats of fresh water to moderately brackish (USDA / illinoiswildflowers.info/ Del Tredici

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Rumex acetosella Red Sorrel	Eurasia / North Africa	Semi-evergreen perennial	Seeds; rhizomes; shoots from root fragments	Disturbance-adapted colonizer of acidic, low-fertility soils, food for wildlife and insects	Full sun; tolerant of drought and acidic and poorly drained soils(Tredici & Pickett, 2010, p. 264)
Rumex crispus Curly Dock	Europe	Herbaceous perennial; up to 5'	Seed (bare ground or buried); established plants resprout from perennial crown, shoots from root fragments	Disturbance-adapted colonizer of bare ground; food for wildlife	Best in full sun, heavy moist soil(Tredici & Pickett, 2010, p. 266)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Schedonorus arundinaceus Tall Fescue	Europe	Evergreen perennial; up to 2'	Germinates readily from seed; expand in size by producing new shoots Tillering enlarges clumps; seeds mature mid-late summer; persist into autumn (Uva et al., 1997, p. 54)	Erosion control on slopes; tolerant of environmental stress	Highly tolerant of drought, low fertility, generally adverse conditions (Tredici & Pickett, 2010, p. 320)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Setaria pumila Yellow / Giant Foxtail	Eurasia	Summer annual	Seeds dispersed when mature head shatters; Germinate late spring, early summer when soil warms; yellow produces tillers	Food and habitat for wildlife	Roadways, abandoned grasslands; moist, rich soil (Tredici & Pickett, 2010, p. 337)
Stellaria media Common Chickweed,	Eurasia	winter annual; up to 1.5 feet	Germinates readily in cool weather; buried seeds remain viable for years; die in heat and drought; can tolerate some mowing	Disturbance-adapted colonizer of bare ground; food for wildlife, particularly birds	Moist, nutrient rich sites, but not limited to such areas; minimally maintained landscapes (Tredici & Pickett, 2010, p. 200)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Taraxacum officinale Dandelion	Eurasia	Herbaceous perennial	Wind-dispersed seeds; sprouts from perennial crown and root pieces	Disturbance adapted colonizer of bare ground; food for wildlife	Tolerates a wide range of growing conditions (Tredici & Pickett, 2010, p. 170)
Thymus serpyllum Creeping Thyme	N. Europe (MOBG Plant Finderwebsite)	Mat forming stoloniferous perennial	Seed, creeping stems root at nodes		Weed of low maintenance turf grass; high pH, dry stony soil (Uva et al., 1997, p. 252)
Trifolium arvense Rabbitfoot clover	Europe	Herbaceous perennial	seed		Sandy soils, drought tolerant (Tredici & Pickett, 2010, p. 226)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Trifolium pretense Red Clover	Eurasia	Herbaceous biennial or perennial; up to 18”	Reproduces readily from seed; established plants produce short rhizomes the give rise to new plants	Disturbance-adapted colonizer of bare ground; important nectar source for pollinating insects; food for wildlife; soil improvement	Grows in a variety of soils; tolerant of mowing, but as much as white clover(Tredici & Pickett, 2010, p. 224)
Trifolium repens White Dutch Clover	Eurasia	Herbaceous perennial	Reproduces readily from seed; stolons spread rapidly rooting as they go; seeds persist in soil	Disturbance adapted ground-covering colonizer; soil improver; browse food for wildlife	Highly adaptable; full sun; tolerant of mowing (Tredici & Pickett, 2010, p. 226)

Plant	Origin	Life form	Germination and regeneration	Ecological function	Habitat
Triodanis perfoliata Common Venus' Looking-glass,		Winter or summer annual, occasionally perennial	Seed, germinates primarily in spring		Weed of low-maintenance turfgrass and landscapes; often found on nutrient-poor, dry, sandy or gravelly soil and on disturbed sites with plants that offer little competition (Uva et al., 1997, p. 188)