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The Greenleaf Farm Resiliency Project: An Ecological Landscape Design

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An Ecological Landscape Design

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Abstract

An ecological landscape design that increases the resiliency of Greenleaf Farm in the face of a changing climate is the basis for this project thesis. It is a comprehensive long-term master plan that integrates various agricultural and land management techniques in an attempt to increase resiliency, i.e. ecological and human/cultural resiliency. Patterns in the landscape inform design decisions and serve as models for agricultural systems. The landscape's tendency to be forested and the goal for production of diverse resources inform the method to integrate ecological goals of the land with greater resilience. Applying the concepts of complexity and diversity to Greenleaf Farm was key to improving resiliency and regeneration. True resiliency in human-altered landscapes depends greatly on the human systems that support it, including the economic system. Economic resilience consists of a diversified production system and income, as well as the cultural systems that keep stewards on the land. Farm resilience means insurance of essential needs by being redundant in sources for those needs. Lasting resilience requires continuous and thoughtful observation rather than thoughtless labor and looking for multifunctionality in all components of a system rather than treating elements as a single product system. Developing a symbiotic relationship to the landscape requires one to think like an ecosystem and cultivate a deeply seeded connection to the surrounding landscape.

Keyword list: Climate Change, Vermont, Permaculture, Agriculture

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Introduction and Overview

Climate change is causing Vermonters to face unprecedented challenges due to increasingly variable weather conditions. Vermont is responding to these changes, especially after the extreme flooding in the spring and summer of 2011 from snowmelt, rain events, and Hurricane Irene. The Institute for Sustainable Communities (ISC) (2014), in partnership with the State of Vermont, is developing the Resilient Vermont Project to help make Vermont a model of community, economic, and environmental resilience. It is evident that Vermonters need to prepare the landscape, economy, and communities for increasingly variable weather patterns and associated changes.

I, in part, own a piece of the Vermont landscape with my father and sister. I grew up on this beautiful piece of land in the rolling wooded hills of the Northeast Kingdom in Peacham, Vermont. Our family farm was largely self-sustainable, producing our own solar electricity, wood heat, vegetables, fruit, beef, hay, maple syrup, honey, chicken, eggs, and goat's milk. Currently, my father is the sole resident of Greenleaf Farm and has largely left the farming business for a musician's life. He still maintains the vegetable garden, orchard, and chickens, but has left the rest of the 463 acres to grow as a Tree Farm and be selectively logged.

I feel that it is my duty to do what I can with this piece of land to help increase the overall resiliency of the Vermont landscape and Wells River of which it is a part. Furthermore, it will become increasingly difficult for my father to maintain the homestead as he grows older. For the purposes of this design project, my father is the client because he is currently the sole permanent resident on the farm. I will always have a deep connection to the land and plan on spending time on the farm post-college and may settle there. It is time for me to start investing my time and energy into building lasting resilience that will benefit the landscape.

I am studying ecological landscape design and wanted deepen my knowledge and experience in the field by completing this design project. I also wanted to build my portfolio because I am planning on attending graduate school for landscape architecture or design. There is an increasingly high demand for ways to live more sustainably in a more ecologically integrated way, and this project will hopefully contribute to the ecological landscape design movement. This background has led me to this goal statement for Greenleaf Farm:

I have created an ecological landscape design to strengthen the resiliency of Greenleaf Farm, and thereby contribute to the ecological resilience of the Wells River watershed and the greater Vermont landscape by predicting, responding, and adapting to changing weather conditions. I have created a long-term master plan consisting of phases that, when executed, will cultivate a productive and bountiful agricultural and forest system that integrates into the natural cycles occurring on the landscape, greatly reducing the need for external inputs and thereby reducing residents carbon footprint. This plan is the beginning of a resilient landscape that strives to be economically viable and largely provide food, fuel, energy, and medicine for current and future residents of Greenleaf Farm.

Review of Literature

This review of relevant literature aims to nest my goals into the larger picture of climate change and the need for resiliency. I will introduce ecological design as an effective approach for this undertaking and ecological landscape design as the catalyst for successful design. Ecological landscape design draws from many ecological approaches to agriculture, which integrate agriculture into the forces and cycles of nature. Reconciling people's interactions and relationship with nature is the key to lasting resiliency. Masanobu Fukuoka sums this idea up beautifully in his quote from *The One-Straw Revolution* (1992), "The ultimate goal of farming is not the growing of crops, but the cultivation and perfection of human beings." David Jacke takes this idea further and writes in Edible Forest Gardens (2005), "The ultimate goal of forest gardening is not only the growing of crops, but also the cultivation and perfection of new ways of seeing, of thinking, and of acting in the world" (Vol. 1, p. 9). By working directly with the land to achieve resiliency and regeneration, we alter our niche in the ecosystem, toward mutualism and cooperation.

Climate Change and the Need for Resiliency

Humans exist in a new epoch, the Anthropocene, in which humans and our societies have become a global geophysical force. This began around 1800 with the rise of industrialization based on the use of fossil fuels (Steffen, 2007). Due to climate change and other human impacts, the Earth is experiencing irreversible dry season rainfall reductions, sea level rise, increased heavy rainfall and flooding, increased storms, loss of permafrost and glaciers, and consequent changes in water supply (Solomon, 2009; Steffen, 2007). These environmental changes have widespread impact on the ecosystems we live in.

In the Northeast of the United States, the altered precipitation and temperatures resulting from climate change will cause changing weather patterns that will include increased hurricanes, ice storms, droughts, floods, and fires. There will also be indirect effects that will cause shifts in ecosystem structure and function of Northern hardwood forests, altering biogeochemical cycling, tree species composition, plant physiology, forest productivity, species composition, length of growing season, quality and quantity of water, pests and pathogens, invasive species, and the physical, chemical, and biological processes of soil (Campbell et. al., 2009). These effects will be profound and complex and will result in a cascading sequence of effects that is largely unknown or under current study.

The Northeast Climate Impacts Assessment (NECIA) team produced a report in 2007, *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions*, that projected the mean annual temperature increase based on both higher and lower greenhouse gas ‘emissions scenarios.’ The higher emissions scenario is if the global community allows emissions to continue to grow rapidly. The lower emission scenario is based on the assumption that the global community makes major reductions in greenhouse gas emissions. NECIA (2007) climate projections found that over the next several decades, temperatures across the northeast will rise 2.5°F to 4°F in winter and 1.5°F to 3.5°F in summer regardless of the emissions choices we make now due to previous emissions. By late this century under the high emissions scenario, temperatures could increase by 8°F to 12°F in winter and 6°F to 14°F in summers above historic levels (NECIA, 2007).

The Vermont Agency of Natural Resources produced a report in 2011, *Climate Change in Vermont* (Betts), which included the following map from NECIA (2007) and gives a visualization of what summer in Vermont will feel like over the course of this century with high and low greenhouse gas emissions.

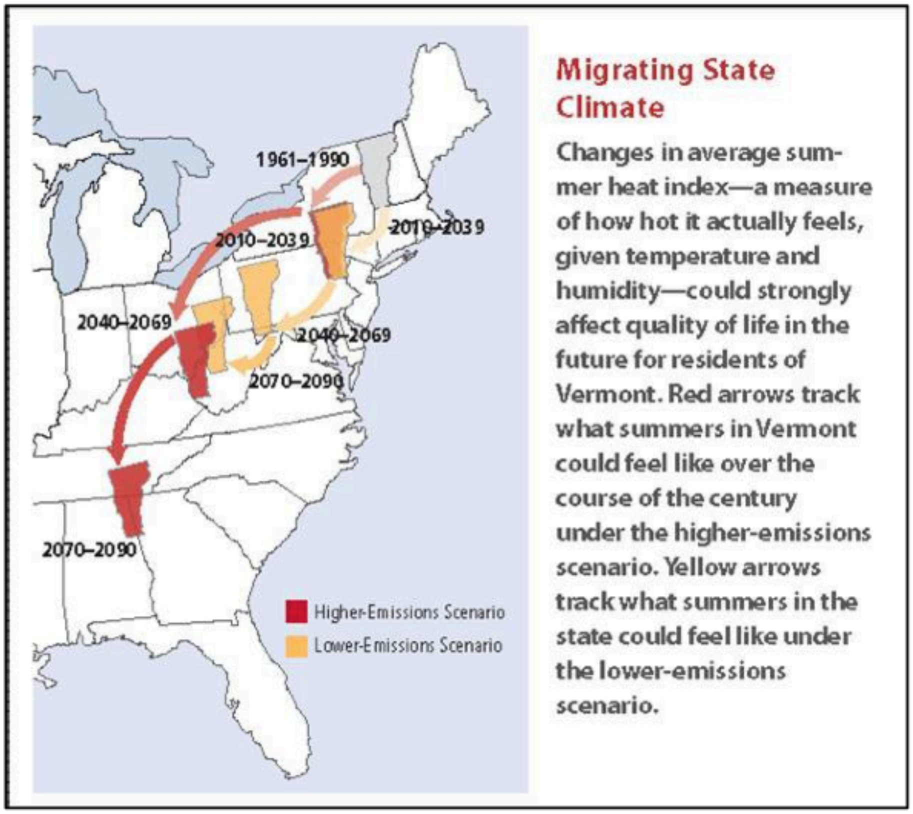

Figure 1. Migrating VT State Climate (NECIA, 2007)

If current high emissions continue, Vermont's summer climate by 2080 will feel similar to the climate of northwest Georgia. However, if emissions are greatly reduced, the climate of Vermont will more closely resemble the climate of southeastern Ohio. If continued high emissions occur, it is projected that by the end of the century, Vermont's precipitation will increase by 15% in winter, 10% in spring, and 5% in fall (Betts, 2011). The increase in precipitation will come in heavy precipitation events (greater than 2 inches in 48 hours) that will increase in intensity by 10 to 15% and in frequency by 12 to 13% by the end of the century in the high emissions scenario (NECIA, 2007). The probability of high flow events in streams may increase as much as 80 percent, accompanied by an increased risk in flooding (NECIA, 2007).

There is already evidence that these changes are beginning to occur with observed changes in weather and temperature and plant and animal species' reactions to these changes. Since 1970, the annual average summer temperatures in the Northeast have increased by 2°F, while the average winter temperatures have increased by 4.5°F (Betts, 2011). Precipitation has increased in Vermont by 15-20% in the past fifty years, with increasing trends throughout much of the year (Betts, 2011). In the Northeast, there has been a 67% increase in the amount of rainfall during very heavy precipitation events (Betts, 2011).

Precipitation increases coupled with temperature increases will cause less winter precipitation falling as snow and more as rain, reduced snowpack in some winters, earlier breakup of winter ice on lakes and rivers, and earlier spring snowmelt resulting in earlier peak river flows (Betts, 2011). Consequently, the length of the winter snow season could be cut in half in Vermont (NECIA, 2007). There will be more runoff from heavier summer rainfall and increased evaporation, causing an increase in the frequency of summer droughts in New England (Betts, 2011). Short term droughts (1 to 3 months) may be as frequent as once a year by the end of the century (NECIA, 2007).
There will also be more frequent days with temperatures above 90°F and a longer growing season (Betts, 2011).

This means that spring is arriving sooner in Vermont, and so are the plant blooming times. Franks et. al. (2007) found evidence for a rapid, adaptive evolutionary shift in flowering phenology after a climatic fluctuation. Phenology is the seasonal timing of reproduction and other life history events in response to ongoing climate change. Bradshaw and Holzapfel (2008) explain that the major effect of these changes on biological systems results from increasing the length of the growing season and altering the optimal time for life-history transitions such as development, reproduction, dormancy and migration. The response of animals to rapid climate change is primarily seen in the northward expansion of species' ranges, the earlier migration and reproduction in the spring, and the later migration or entrance into hibernation in the fall (Bradshaw & Holzapfel, 2008).

The changing climate has many implications specific to agriculture. NECIA (2007) predicts that an increasing number of storms producing heavy rainfall may delay spring planting and damage crops and soils. Frequent droughts during the growing season could make irrigation essential for most crops. There will be a longer growing season with earlier first-leaf and first-bloom dates for plants. This longer growing season may allow farmers to experiment with new crops but many traditional farm operations will become unsustainable without adaptation strategies. Parts of the Northeast are projected to become unsuitable for growing certain varieties of apples, blueberries and cranberries since they require long winter-chill periods to produce fruit. Weed problems and pest-related damage are likely to escalate. Farmers in the Northeast will face uncertainty and risk as they attempt to adapt to the effects of climate change.

Walker and Salt (2006) explain resilience as the ability of a system to absorb disturbance and still retain its basic function and structure. The landscape of Vermont is a socio-ecological system threatened by changing environmental conditions and may be approaching a threshold due to climate change. If a system changes too much it crosses a threshold and experiences a "regime shift" which means a different structure and function of a system (Walker & Salt, 2006). Crossing a threshold alters the premises that current agricultural practices are based on and can pose challenges to the farmer or landowner.

Socio-ecological systems change over time, called systems dynamics. There are four phases that systems usually undergo, called their adaptive cycles, including rapid growth, conservation, release, and reorganization (Walker & Salt, 2006). These cycles operate over many different scales of time and space and focus on processes of destruction and reorganization in order to understand complex systems and the resilience inherent in them. The adaptive cycle exhibits two major transitions; the first is from growth to conservation (the foreloop), defined by slow and incremental growth and accumulation. The second (backloop), is the rapid phase of release and reorganization leading to renewal (ie. resilience). It is essential to build connectedness and stability as much as possible in the foreloop in order to be prepared for brief windows of experimentation and disturbance and reduce severity of the backloop. This includes building nutrients and biomass in ecosystems and building skills, networks of human relationships, and mutual trust in economic or social systems (Resilience Alliance, 2014). To increase resiliency, the nature of the system must be transformed to minimize losses by responding and adapting to thresholds. Walker and Salt (2006) advise, "at the heart of resilience thinking is a very simple notion—things change—and to ignore or resist this change is to increase our vulnerability and forego emerging opportunities" (pg. 9-10). Agricultural and land management practices must be adapted to these changes in ecosystem structure and function driven by climate conditions.

So what makes a landscape resilient? Ecosystems are in a constant state of dynamic change, yet they are relatively stable due to their complexity and species diversity (Gliessman, 2007). Due to complexity and diversity, ecosystems can either resist disturbance or be resilient post-disturbance. The recovery of a system after disturbance is a process called succession, which eventually allows the state of the ecosystem to return to something close to its original state (Gliessman, 2007).

The goal of my design was to intervene in the succession from pasture and hay fields to forested land and increase species diversity and community complexity as well as increase the productivity of the agricultural systems by integrating them into the succession process. This idea was aided by work where a team of scientists set out to answer the question: can a mimic of a natural successional community develop the emergent property of self-renewing fertility like the model? (Jacke, 2005). They found that an enriched succession (human-intervened) performed better than any other treatment, retained more nutrients and produced more root mass. Permaculturist Ben Falk states in his book, *The Resilient Farm and Homestead* (2013), "Human work…can *speed* the healing of more-than-human systems. As said in the permaculture community, 'We are nature working.'"(p. 1). We are not only working with nature, we *are* nature creating life-supporting systems around us to nourish ourselves and future generations

Ben Falk (2013) states, "These systems… must be simultaneously regenerative and resilient, for without regeneration, health and production are limited" (p. 1). A human-supporting system needs to be intrinsically productive in order to be resilient. Something is regenerative when it accelerates the process of transforming mineralogical matter into complex living organisms (Falk, 2013). Resiliency and regeneration go hand in hand, working together to adapt and generate abundance.

Ecological Design

Ecological design is based on a deeply rooted land ethic. Aldo Leopold first introduced this ethic in his book, *A Sand County Almanac* (1949): "A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise" (p. 262). Leopold expanded on this in his essay, *The Ecological*

Conscience (1947), stating, “the [biotic] community includes soil, waters, fauna, and flora, as well as people.” Ecological design follows this ethic of “nature as measure” (Jackson & Berry, 2011) emphasizing that the health of the land is the health of people.

Ecological design provides a holistic framework to create resilient and regenerative cultivated human habitats. Ecology is derived from the Greek words oikos, meaning “household”, and logia, meaning, “study of” (Jacke, 2005). Ecology is the study of the world as our household; how we and all the other factors that make up the world interact and find a home. There are several key ideas that form the basis of ecological systems. The first idea is that every organism is somehow connected to every other organism, as well as nonliving elements in the world (Jacke, 2005). Therefore, when one factor of an ecosystem changes, it influences all other factors of that ecosystem in some way, directly or indirectly. The second idea is that the structure and functions of an ecosystem give them relative stability and resilience (Jacke, 2005). An ecosystem is made up of physical parts that interrelate—the structure of the system—that together take part in dynamic processes—the function of the system. The basic structural components of an ecosystem are biotic factors, the living organisms that interact in an environment, and abiotic factors, the nonliving physical and chemical elements of the environment such as soil, moisture, light, and temperature (Gliessman, 2007). The two most fundamental processes in any ecosystem are the flow of energy among its components and the cycling of nutrients (Gliessman, 2007). If too much of a nutrient is lost or removed from an ecosystem, it can limit further growth and development. Productivity in agriculture is very closely tied to the rates at which nutrients are able to be recycled in a system. The third key idea is that ecosystems change discontinuously and are complex beyond what we can understand (Jacke, 2005). Discontinuous change means that times of stability can be followed by great changes at any scale. The resilience approach focuses on the dynamic interplay between periods of gradual and sudden change and how to adapt and shape change (Walker, 2007).

The number of relationships among ecosystem elements is profound and beyond human inquiry or comprehension, but we can try to understand it to the best of our abilities in order to make informed decisions. The relationship between humans and nature is deep and complex; it can be harmonious if we follow certain guidelines, and it can be disastrous if we don’t. We have to figure out the guidelines ourselves with only subtle hints provided by nature. The best way to understand the nature of our world is to observe and emulate it. What greater library do we have than the 3.8 billion years of life that has adapted to the current conditions of our world? Sim Van der Ryn, chairman and chief designer of the Ecological Design Institute, and Stuart Cowen, an ecological designer, propose “in order to integrate ecology and design, we must mirror nature’s deep interconnections in our own epistemology of design…. It is time to stop designing in the image of the machine and start designing in a way that honors the complexity and diversity of life itself” (Ryn, 1996, p. x). Furthermore, it is important to understand the local ecology, not just ecology in general. Alexander Pope wisely advises, “to consult the genius of the place in all” in his poem, *An Essay On Man* (1734) (part of poem found in Appendix Q). David Jacke (2005) affirms,

> We seek to learn—from our own fields, thickets, forests, and wetlands—the ways in which living things have adapted to our climate and land. We want to mimic these habitats with productive garden ecosystems. The goal is to create mutually beneficial communities of multipurpose plants for our own sustenance, and thereby to include ourselves in the natural world (p. 7).

Ecological design celebrates the genius or spirit of place and allows it to inform designs. It also integrates the diverse human dimensions of economics, aesthetics, community social patterns, recreation, transportation, and sewage/waste handling into nature’s biological patterns and physical processes (Thompson & Steiner, 1997). Ecological design is as much about designing with natural systems as it is about designing with human systems. Proper design and conservation of the environment promotes the ecological health and liveability for humans, which create a stronger sense of community and good citizenship (Minteer, 2006).

Ecological landscape design provides the catalyst to effectively design, implement and maintain resilient and regenerative human habitats. Landscape design with an ecological approach transforms the field of creating anthropogenic landscapes from being part of the problem of the built environment to part of the solution by integrating human processes and ecological processes. It draws from ancient ideas that have sustained human population for thousands of years and applies them to the present day in order to adapt and flourish.

Ecological Approaches to Agriculture

It is important to remember that peoples around the world have been applying concepts of ecological design to their cultivated landscapes for thousands of years in order to be resilient and provide for future generations. The Great Law of the Iroquis Native Americans states, “In every deliberation, we must consider the impact on the seventh generation... even if it requires having skin as thick as the bark of a pine”, making regeneration a priority. The peoples of tropical Africa, Asia, and Latin America have a long tradition of multi-storeyed agriculture (Jacke, 2005). They integrate trees, shrubs, livestock, and herbaceous crops in what we now call agroforestry. The Yanomamo of the Amazon rainforest deliberately propagate hundreds of plant species, which enhances the biological diversity of the ecosystem (Ryn & Cowan, 1996). Balinese aquaculture and rice terracing maintain soil fertility and purify water while feeding many people (Ryn & Cowan, 1996). Australian aborigines use stories and rituals to preserve an amazingly detailed ecological map of their lands (Ryn & Cowan, 1996). Ecological approaches to agriculture exist in many cultures around the world, many times out of necessity. An intensive land use system called coppice forestry was used throughout Britain and continental Europe beginning at least in the Middle Ages, where the suckers growing out of stumps were harvested for fuel and fodder. However, coppice forestry systems almost disappeared during the Industrial Revolution (Jacke, 2005).

Ecological landscape design largely draws from various ecological approaches to agriculture with a goal of food and other resource production with fewer external inputs. My work has been highly influenced by the fields of natural systems agriculture, agroecology and permaculture, which all “attempt to follow natural systems (including native efficiencies, natural productive strategies, and ecological limits) much more closely than the standard industrial paradigm” (Minteer, 2006, p. 161). The most important characteristic of ecological agriculture is coherence, expressed by Wendell Berry in his introduction to Wes Jackson’s, *Nature as Measure* (2011). This coherence is centered on place and all the natural and human elements pertaining to it, or as Berry (2011) expresses, “the effort of the best farmers to adapt their farming to their farms” (p. xi). By emulating various characteristics of local ecosystem structures such as species diversity and habitat heterogeneity, farms benefit from functional processes such as nutrient cycling, shade and wind protection, pest management, competition, symbiosis, and successional changes (Imhoff, 2003).

The challenge in creating truly resilient agricultures is to achieve natural ecosystem-like characteristics while maintaining productivity and harvest output. If a farm or homestead is not economically viable then it will not be truly resilient because the people will likely leave. Methods to achieve this include designing systems so that energy flow can depend less on non-renewable sources and a better balance can be achieved between energy maintained in the system for internal processes and the energy available for export. Nutrient cycles should be designed to be as closed as possible, keeping as much nutrients in the system as possible and finding sustainable ways to replenish lost nutrients. Population regulation of pests can be designed to depend on system level resistance from various mechanisms such as increasing habitat diversity and ensuring presence of natural enemies and antagonists (Gliessman, 2007, p. 31).

As discussed earlier, applying the principles of complexity and diversity are essential for system resiliency because the higher the diversity, the higher the potential for beneficial interactions. Emergent qualities that develop from ecological interactions and synergies between a high diversity of biological components are maintenance of soil fertility, productivity, and crop protection (Imhoff, 2003). Crop rotations, polycultures, agroforestry, and animal integration are examples of methods that promote self-sustaining dynamics. Diversity can exist on the community level with plants and animals, but it should also exist in different dimensions. There can be diversity of spatial arrangements, such as the different canopy levels in a forest or use of landscape patchiness (ie. a forest, field, and wetland in proximity). There can also be temporal diversity, which means change in various ways over time, cyclically and directionally. This could mean planting different crops in the same place each year or working with stages of succession (Gliessman, 2007).

A crucial part of ecological landscape design is *relationships*; it is not just about the elements themselves, but how they are placed in the landscape. Just like an ecosystem, human systems must adapt to the optimal and most resource efficient way of life. The principle of relative location means that every element (such as house, pond, road, etc.) is placed in relationship to another so that they assist each other with needs and yields. Bill Mollison (2011), founder of modern-day permaculture, affirms that this type of thinking and design requires continuous and thoughtful observation rather than thoughtless labor. It requires looking for multifunctionality in all components of a system rather than treating elements as a single product system. Redundancy of essential functions, such as water sources and food production and storage, is key to remaining resilient in times of great change.

Climate Changes and Design Solutions

The concept of resiliency in landscape design is an adaptive response to the challenges that climate change poses. In the following section, I will highlight key predicted weather changes and some design solutions to deal with these changes. Many of these design solutions come from the permaculture courses I have taken with Itai Hauben (2013) in Costa Rica and Keith Morris (2014) at University of Vermont.

Vermont will see more hurricanes, heavy precipitation events, and floods. These events will increase in intensity as well as frequency (NECIA, 2007). Solutions to confront these potentially devastating events attempt to slow, spread, and sink water on the landscape to reduce erosion and other harmful effects. Retention ponds capture large amounts of water and disperse the impact of water on the landscape. Swales, terraces, paddies and keyline ditches capture water along contour and allow infiltration to occur, reducing water runoff and erosion. Not only does capturing water reduce runoff, it also replenishes groundwater and keeps valuable nutrients in the system. Methods to reduce water runoff and soil erosion in agricultural fields include planting cover crops, green manure crops, and implementing reduced-till or no-till systems. Cover crops and green manure build organic matter and nutrients in the topsoil while also suppressing weeds and potentially providing habitat for beneficial insects. Reduced-till or no-till systems maintain soil aggregates and healthy soil communities. Rain barrels and rain gardens capture water from impervious surfaces to protect the surrounding area from storm water impact and provide an alternative source of water. Planting flood tolerant crops and water-loving species like cranberries and elderberries is a way to take advantage of the increased availability of water in the landscape (Jacke, 2005). Rice paddies are an excellent way to adapt to climate change; they slow water running off the land, they take advantage of the wetter weather conditions, and they welcome the warmer temperatures in Vermont to provide an essential source of grain (Falk, 2013).

Vermont will see more droughts during the growing season, which will stress water availability and food production (NECIA, 2007). It will be important to be redundant in water sources to ensure year-round supply. Multiple sources of water could include a freshwater spring (primary source), a pumped well (secondary source), and a potable rainwater collection system as a tertiary source. Having a pond at a higher elevation than a homestead is important to have a year-round source of irrigation water that only relies on gravity for dispersal. It is important to conserve soil moisture with diverse and dense plantings. Furthermore, we can adapt to these changes by planting hardy drought-resistant plants that don't require as much irrigation such as alder and yarrow (Jacke, 2005).

There will be less snow cover on average in the winter, which will stress plants because snow cover acts as a natural insulator (NECIA, 2007). Some methods to protect plants from the cold winter temperatures could be to mulch vulnerable plants with straw or wood chips, build snow fences to create drifts in areas that could use more insulation, and create microclimates with rocks that have thermal mass and can warm the area around them.

Premature thaws and earlier snowmelt threaten plant phenology by forcing them to bud out early, making them vulnerable to late frosts. Ways to adapt to these changes is to plant species that tend to bud out later in the spring and won't be susceptible to premature thaws. Methods for season extension will become increasingly important in Vermont to provide a regulated environment in these increasingly variable weather conditions. Strategies for season extension include simple measures such as cold frames and low tunnels to more complex systems such as greenhouses, hoop houses, and high tunnels to protect plants from the elements.

Other weather extremes we can expect to see are increased wind and hail (NECIA, 2007). Planting species less susceptible to wind and hail will reduce frequent storm damage and growth setbacks. Species that are resistant to disturbance such as black locust or resilient post-disturbance such as poplar are key in the landscape. Planting wind buffers is critical to protecting crops, buildings and livestock from the effects of heavy winds. Windbreaks create important microclimates with protection from cold winter Nor'easters while creating warm southwestern exposures.

Increased average temperatures will mean longer growing seasons and a migration of animal and plant species northwards (NECIA, 2007). We can take advantage of these changes by planting species that have not historically survived here such as peaches, rice, and various nut trees. Oak and hickory will become a dominant forest type in Vermont and we can adapt to this by taking advantage of nut production. In addition, we will have to be wary of pests and pathogens that may not be killed off by cold winter temperatures any longer. Improving the effectiveness of pest, disease, and weed management practices, through wider use of integrated pest and pathogen management and use of varieties and species resistant to pests and diseases will be critical (Howden et. al., 2007). Building healthy topsoil with diverse microbial organisms and mycelium is essential to protecting plant health from pests and pathogens.

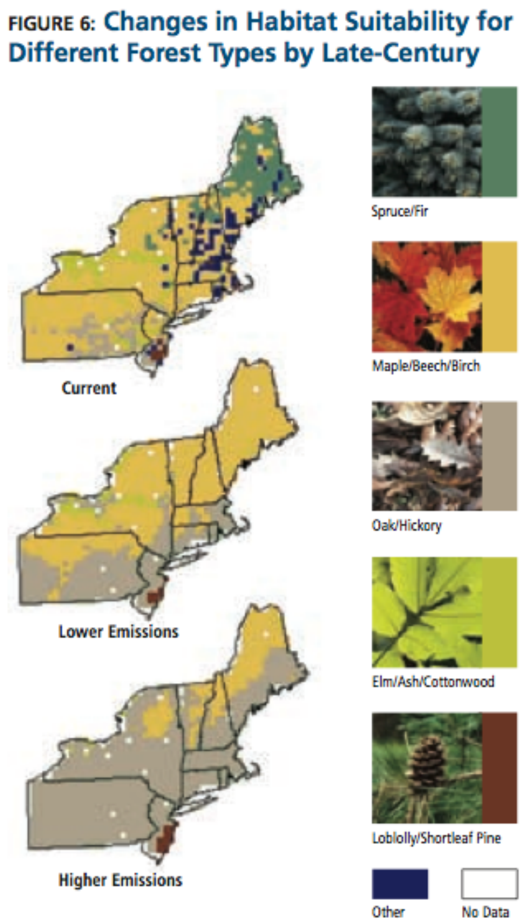

Figure 2. Changes in habitat suitability for different forest types by late century (NECIA, 2007)

Not only will changing weather conditions increase in magnitude and frequency, they will become increasingly variable and hard to predict (NECIA, 2007). This will make it difficult for farmers and homesteaders to rely on one source of production and income. Diversifying income through integration with other farming and production activities such as raising livestock or value-added products will be essential (Howden et. al., 2007). Using climate forecasting to reduce production risk as much as possible will allow time to respond and prepare for these changes. Altering varieties/species to those with more adapted thermal time, vernalization requirements, and increased resistance to heat shock and drought will be key to a resilient agricultural system (Howden et. al., 2007). These agricultural adaptations have substantial potential to offset negative climate change impacts and to take advantage of positive ones (Howden et. al., 2007).

The following strategies have been proven to increase resiliency in an agricultural system. I will be focusing on three sectors: soil and water, biological (plants), and wildlife and livestock.

Soil and Water

The interaction between soil and water is the basis for resilient systems. A successful water and soil interaction can provide irrigation, replenish groundwater, increase fertility, and promote regeneration. Creating more surface area with earthworks creates more interface, which determines regeneration (Falk, 2014). For example, swales are ditches dug on contour that capture water runoff, allow it to infiltrate and replenish groundwater, increase interface and provide a perfect microclimate to grow productive perennials such as a seaberry, plum and hazelnut system with nitrogen fixing clover and dynamic bioaccumulating comfrey. Ponds situated above production areas provide alternative sources for irrigation if other systems fail, increasing the resilience of the system in dry times. Permaculture designer Keith Morris states that soil and soil health is the most effective preventative medicine we have. Healthy soil aids a plant in its ability to resist pest and disease and increases its water and nutrient uptake. Methods to increase topsoil and develop a more nutrient balanced and diverse soil include biomass composting, humanure, biochar, and Effective Microorganisms (EM). EM is a recipe made with ectomycorrhizal fungi found in the forest and applied to gardens.

Forest productivity, recovery, and stability depend on organisms and processes in the soil. Ectomycorrhizal fungi (EMF) profoundly affect forest ecosystems by mediating nutrient and water uptake, protecting roots from pathogens and environmental extremes, and maintaining soil structure and forest food webs (Amaranthus, 1998). "Diversity of EMF likely aids forest ecosystem resilience in the face of changing environmental factors such as pollution and climate change" states Amaranthus (1998, p. 1), a research biologist. Strategies for conservation of EMF include decreasing levels of environmental pollutants and retaining diverse assemblages of native host species, habitats, and structures across a landscape. An estimated 50 to 70 percent of the net annual productivity of a forest may be attributed to roots and associated mycorrhizal fungi (Amaranthus, 1998). This is significant when agricultural systems are integrated into the forest ecosystem.

Biological (Plants)

The biotic elements in an ecosystem play a key role in system resilience. They operate in a complex web of interrelationships that are resistant to disturbance or resilient post-disturbance. The structure of these relationships determines the various functions that they provide for the system. Emulating natural productive strategies such as diversity and density is essential in order to benefit from native efficiencies. Diversity increases the complexity of relationships and allows for beneficial ones to emerge. Density retains soil moisture and regulates soil during dry and wet times while also suppressing weeds and providing system-level resistance to pests and pathogens when coupled with diversity. Sometimes these relationships can be anticipated by companion planting (for example, corn, beans, and squash). Some important ecological functions that increase regeneration and resilience are bioaccumulators that mine minerals and nutrients from deep in the soil and bedrock, nitrogen fixing plants and trees that form symbiotic interactions with mycorrhizal fungi, and plants with extensive root structure that reduce erosion and increase health and fertility of the soil.

The Land Institute is devoted to exploring and promoting the possibilities of a sustainable agriculture model based on the native prairie ecosystem in the Midwest (Minteer, 2006). Research at The Land Institute has proven that high-producing perennials are possible and that in many cases, perennial polycultures have the potential to out yield seed crops grown in monocultures (Minteer, 2006). In addition, it is evident that mixed perennials can effectively manage weeds, pathogens, and pests and fix their own nitrogen due to greater genetic and species diversity (Minteer, 2006). When crops are native and mimic natural productive strategies, they often benefit from native efficiencies.

A landscape covered in perennial plants, as opposed to annuals, commonly found in agricultural systems, transforms subsoil (mineral soil) into topsoil (organic-matter-rich material) with each passing year (Falk, 2013). The rooting capacity of perennials brings organic matter, water, and biological activity into the subsoil while also drawing from valuable minerals and nutrients deep in the soil. This root-soil interaction builds organic soil and improves the plants capacity to grow and produce. Diverse perennial systems typically capture between three and seven times the amount of solar energy as annual croppings, found through various studies and is well documented, especially by Mark Shepherd at his New Forest Farm in Wisconsin (Falk, 2013). Perennials ability to grow deeply into the soil horizon allows a very crucial advantage with increasing variability in climate: drought resistance. Deeper roots allow perennials to mine deeper water tables and moisture that evaporates from the surface downward (Falk, 2013). Perennials also offer a high degree of flood resilience by withstanding seasonal inundation as long as they are not exposed to high-flow velocities (Falk, 2013).

A perfect example of an integrated agriculture is an edible forest garden, which is a perennial polyculture of multipurpose plants that provide diverse resources for people such as fruit, nuts, timber, and medicinal herbs. Edible forest gardens mimic forest structure and benefit from the self-renewing, self-fertilizing, and self-maintaining functions of forests (Jacke, 2005). Temperate forests net *twice as much energy* as conventional agriculture (net primary production of biomass) (Jacke, 2005). In addition, diverse crops can result in higher net yields than conventional agriculture due to symbiotic relationships between biota.

The “three sisters” system used by the Iroquois of corn, pole beans, and squash provides multiple benefits because the beans grow up the corn stalks and fix nitrogen while the wide leaves of the squash prevent weeds from growing and conserve water by acting like a natural mulch, reducing the need for external energy inputs (Jacke, 2005). In addition, the diverse species provide habitat for beneficial insects such as natural pest antagonists and pollinators. Ecological gardens build “strong connections among the plants, soil life, beneficial insects and other animals, and the gardener, to weave a resilient, natural web” (Hemenway, 2000, p. 5), just like nature.

The Rodale Institute has done research on alternative agricultural methods and has found that organic manure-based and organic legume-based plots out yielded the conventional plot by significant margins in years of drought, severe drought, and hurricane-driven torrential rains (Lotter et. al., 2003). Soils in the organic plots captured more water and retained more of it in the crop root zone than in the conventional treatment. Water captured in the organic plots was approximately 100% higher than in conventional plots during the torrential rains (Lotter et. al., 2003). Therefore, use of organic manure and legume cover crops increased the resiliency of the system in extreme weather events. These ideas are applicable to soil as well, but I wanted to highlight the importance of cover crops and minimizing the occurrence of open soil to reduce erosion and maintain healthy soil structure.

Wildlife and Livestock

Providing habitat and support for wildlife is critical for improving biodiversity and thus, resilience. Methods to provide diverse habitat niches include: diverse and dense native plantings that provide nectar, pollen, fruit, nuts, and berries, earthworks to increase water sources and edge effect of various habitat types, and man-made shelters such as bird, bee, and bat houses.

Creating habitat for beneficial species to plant productivity is essential for pollination and system-level resistance of pests and diseases. Beneficial insects include pollinators such as native bees and natural pest antagonists such as parasitic wasps or ladybugs. Native bees are important pollinators of many crop plants, and natural patches enhance pollinator services and crop yield. In a study of canola growers in Canada, it was found that in the absence of honeybees, the growers could increase profit by turning 30% of their productive land into pollinator habitat, instead of planting it to canola (Monandin & Winston, 2006). Not only does creating pollinator habitat increase production, but it also provides increased biodiversity and resiliency.

Integrating livestock into food production systems with rapid and intensive rotational grazing schemes can build soil while also providing fodder (Falk, 2014). Goats and pigs are excellent for system establishment because they dig up tough plants like juniper and they till and aerate the soil. Ducks and chickens provide excellent sources of fertilizer from their manure. They also help with pest control, weed suppression, and they scratch and till up the soil. Larger livestock can include sheep and cattle, but must be managed intensively so as not to harmfully affect crops.

Adaptive Management

Managing ecological systems entails taking advantage of the emergent qualities of the system, which shifts the management paradigm from controlling conditions and populations to the paradigm of managing them.

Fikret Berkes et. al. (2000) researched Traditional Ecological Knowledge (TEK) as adaptive ecosystem management because it utilizes feedback learning, meaning that people interpret and respond to feedbacks from the environment to guide management. Some examples of the methods used are multiple species management, resource rotation, succession management, and landscape patchiness management (Berkes et. al., 2000). Berkes et. al. (2000) found that the way in which values and practices are sustained (cultural systems) is just as important as the practices themselves. Resource management from a TEK point of view includes processes for the generation, accumulation, and transmission of knowledge and desirable worldviews and cultural values, which are all integral to true and lasting resiliency (Berkes, 2000).

Pre-settlement forests in Vermont were dynamic, shaped by natural and human influences and disturbances that profoundly affected the forest ecosystems and resulted in immense diversity of forest conditions, illustrates Douglas MacCleery in his book, *Resiliency and Recovery* (1994). "Primeval" forests during the time of Native Americans were, in fact, human managed ecosystems used to increase and diversify food supply and improve living conditions (Jacke, 2005). Temperate deciduous forests were the home of a range of species second only to the tropical rain forest in their diversity due to native agroforestry (Jacke, 2005). Fire was a major management tool of the native peoples of North America; many used "swidden" (slash and burn) to clear forest patches in order to grow crops (Jacke, 2005).

The forests in North America today are fragmented; they are no longer the dominant feature of the landscape. Forest fragments contain diminished biological diversity and cannot as easily absorb and hold rainfall or perform other essential ecological functions (Jacke, 2005). Loss of forest cover also alters the local and regional climate, increasing temperature and moisture extremes in the landscape. Forests significantly moderate winter temperatures and winds and reduce summer temperatures.

They also moderate both flood and drought and help to sustain the “base flow” in streams and rivers (Jacke, 2005).

Managing the landscape adaptively means converting land back to forests and creating forest corridors to connect wildlife populations. Howden et. al. (2007), suggests some adaptation strategies for planted forest management, including changes in management intensity, hardwood/softwood species mix, timber growth, harvesting patterns, rotation periods, salvaging dead timber, shifting to species or areas more productive under new climatic conditions, landscape planning to minimize fire and insect damage, and adjusting fire management strategies for pest and disease management. These proactive measures may potentially reduce the negative consequences of climate change suggests Howden et. al. (2007).

The ability to read and respond to the landscape is integral to adaptive management. Reading the landscape means being able to observe processes and interactions as a feedback mechanism, and changing management strategies according to the health and productivity of the land.

Methods

Site Context

Greenleaf Farm lies in the northern forest biome of Eastern North America. This humid cold-temperate region is dominated by strong seasonal variations in day length and temperature. The climate is also driven by westerly winds with occasional arctic and maritime events. This region of rolling hills was heavily altered by the last glaciation about 13,000 years ago. Vegetative cover consists of the northern extent of the great hardwood forests of eastern North America. The site is within the town of Peacham in the state of Vermont in the United States of America.

Site coordinates: 44°16'N, 72°11'W (Google Earth, 2014).

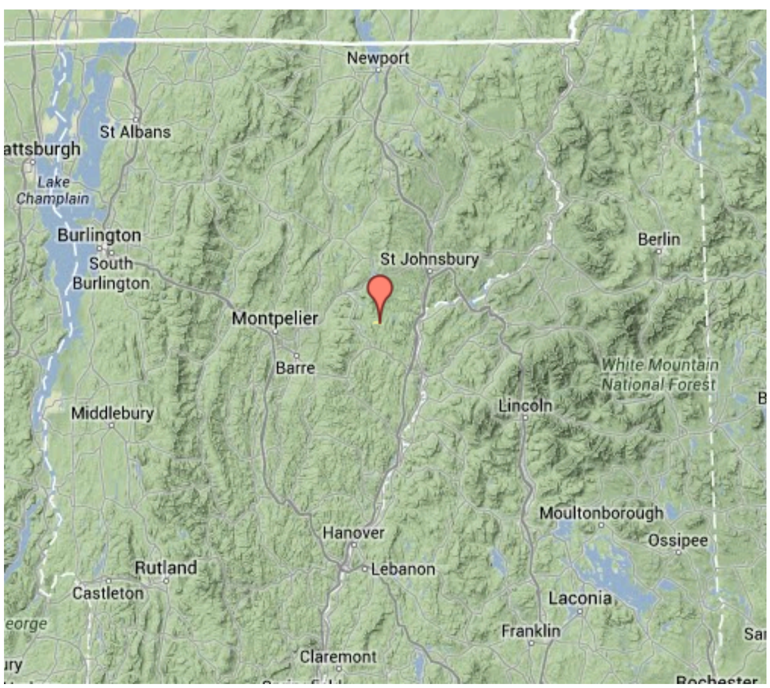

Figure 3. Site location in relation to State of Vermont (Google Maps, 2014)

The site is in the Northern Vermont Piedmont biophysical region (Thompson & Sorenson, 2005, p. 44-47). The Northern Vermont Piedmont has a climate that is moderate; it is cooler and moister than the Champlain Valley and warmer and dryer than the Green Mountains or the Northeastern Highlands. The metamorphic rocks of the

Northern Vermont Piedmont are generally calcareous, making for calcium-rich soils. The soils are comprised of glacial lake deposits of coarser texture, primarily sand.

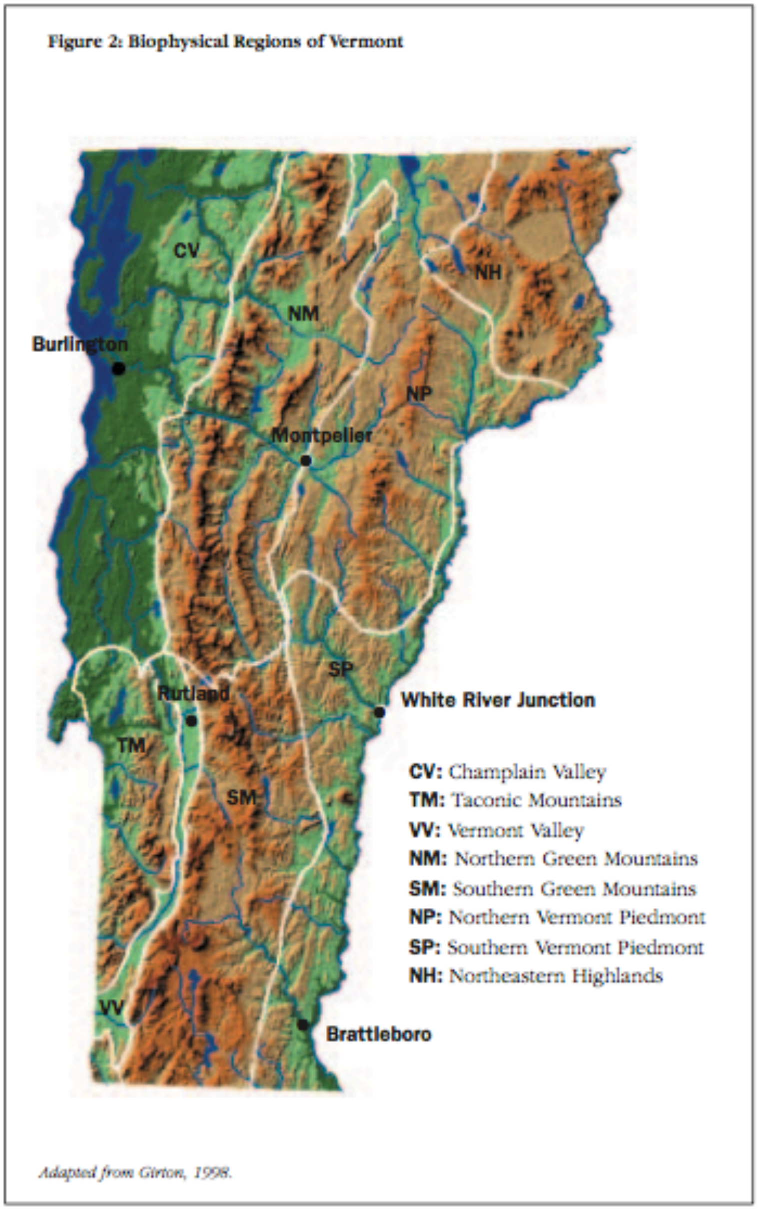

Figure 4. Biophysical Regions of Vermont (Thompson & Sorenson, 2005)

Situated in the rolling hills of Vermont between the Green Mountains and the White Mountains, Greenleaf Farm is just west of the Connecticut River Valley. The White Mountains of New Hampshire are visible to the east from several vantage points on the property. The site is adjacent to Groton State Forest, consisting of 28,000 acres of protected land. Water on the site drains into the northern branch of the Wells River, which flows south into Wells River, which flows into the Connecticut River. The Connecticut River flows south dividing Vermont and New Hampshire, emptying into Long Island Sound and eventually the Atlantic Ocean. The site's position on the southeastern slope of Lost Mountain increases its exposure to southwestern prevailing winds and limits its exposure cold northwest prevailing winds. This position also offers ample early morning sunshine and southern sun exposure. Greenleaf Farm is about a 30-minute drive to St. Johnsbury, the closest big town, and about a 45-minute drive to Montpelier, the state capital.

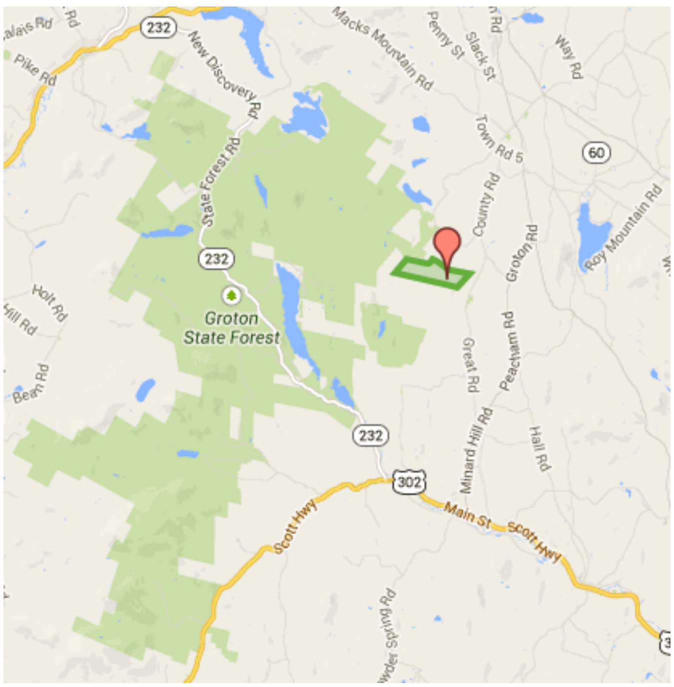

Figure 5. Relative location to Groton State Forest (Google Maps)

Greenleaf Farm's 463 acres encompass the top of Lost Mountain and stretch over its slopes to the east, south, and west. Groton State Forest borders the property to the west and is the second largest contiguous land holding of the State of Vermont. Groton State Forest is known for its scenic and rugged terrain, offering numerous recreational opportunities. A year round trail system connects most major points of interest in Groton State Forest, including Peacham Bog which lies just northwest of the property. The state road skirts around the northwest corner of the property. Peacham Bog Natural Area contains the second largest peat land in Vermont, one of the two "raised" bogs in the state. Vermont Association of Snow Travelers (VAST) maintains a snowmobile trail that connects to the state road at the northwest corner of the property and runs southeast to the middle of the southern boundary line.

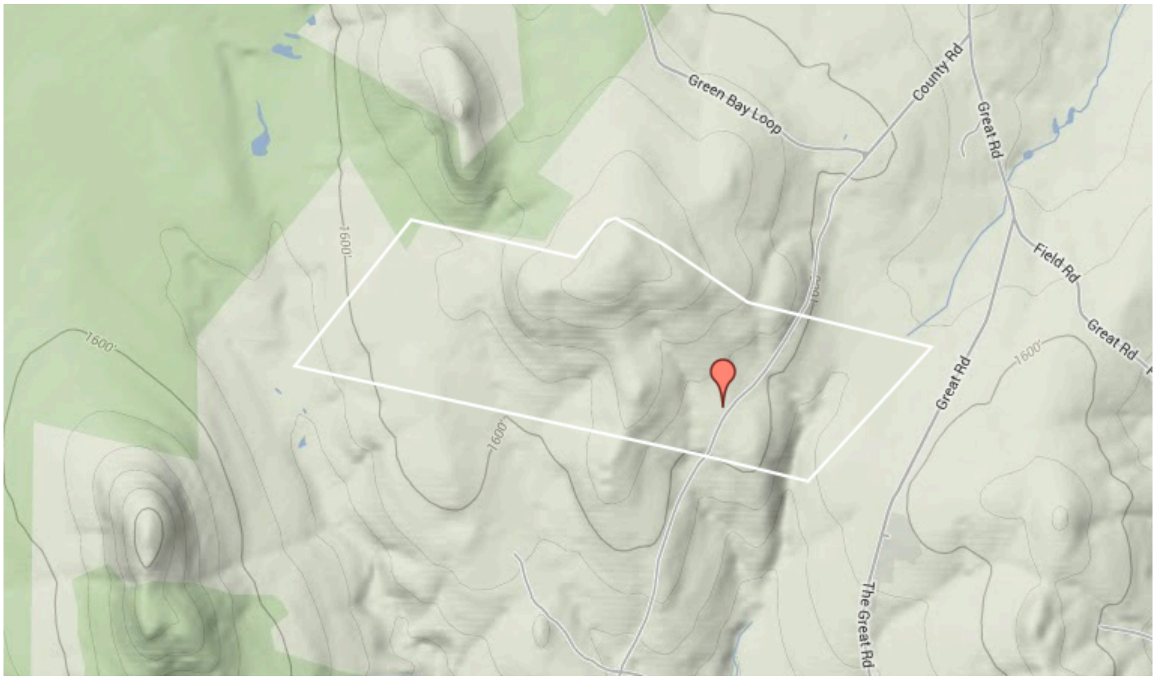

Figure 6. Topography (Google Maps)

Vertical relief on the property is 540', ranging from 1480' above sea level in the southeastern and southern corners to 2000' at the top of Lost Mountain in the northernmost area of the property. The property generally slopes to the south with significant southern and southeastern aspects on moderate slopes. Red Brook drains the western edge of the site while the northern branch of the Wells River drains the remainder. The site is dominated by Northern Hardwood Forest with some areas of mixed wood (hardwood and softwood). There are also some areas of Hemlock-Northern Hardwood Forests, especially in the southwest corner of the property where it is sandier and wetter. Softwood forest covers the southeastern corner of the site in the lower elevations. Lowland Spruce-fir forest and northern white cedar swamp emerge around the wetland areas in the northwest and northeast corners of the property.

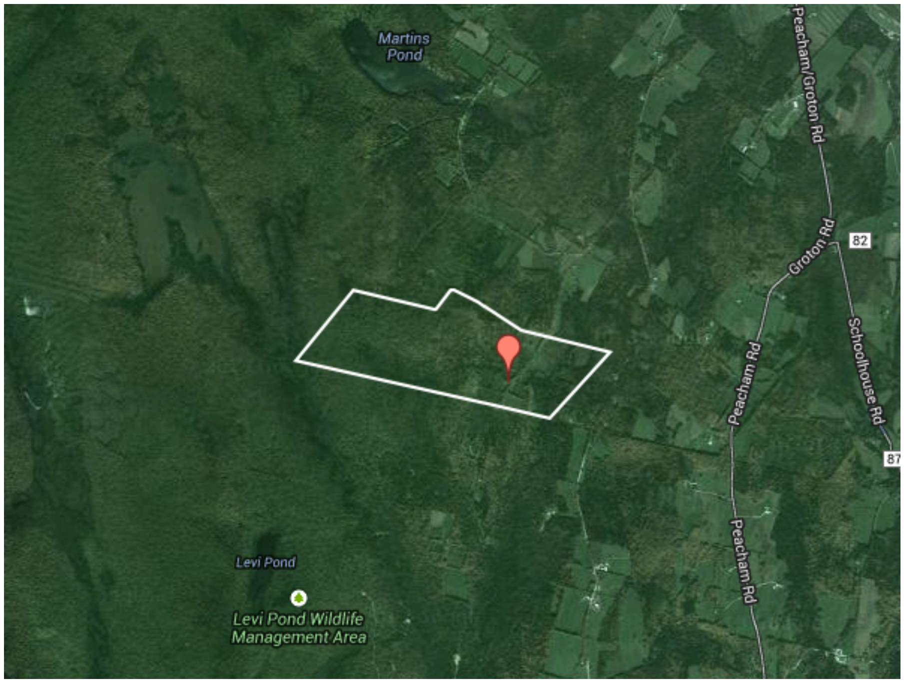

Figure 7. Base Map with satellite imagery (Google Maps, 2012)

The landscape is in a constant state of succession, evolving to what the land wants to be—old growth forest. The fields on Greenleaf Farm are undergoing early stages of succession, transforming from old pasture and hay fields to forests. Historically, it was farmed as a beef cattle operation on a small scale until 2003. Since then, nature has taken over and the 60 acres of fields are undergoing the early stages of succession. Some fields have been bush hogged in the past couple of years and are in an earlier stage of succession than others. The rest of the farm consists of 400 acres of forest, managed as a Tree Farm by the client and his timber management company, LandVest. The goal of the client and his forester is to make timber yields have the maximum value over a long period of time. The key to a successful design is a harmonious convergence of the landscape's goals, the client's goals, and my own goals.

Design Approach

I used an ecological design approach that was integrative and adaptive to the complexity of the landscape. This integrative approach recognized that an action taken at any point in the process of designing, establishing, or maintaining a landscape would influence every other point in the system (Chase-Rowell, 2007). It is the same with an ecosystem; the inherent interconnections cause change throughout the web of causality when one aspect changes. The model of design from the Conway School of Landscape Design (2012) is GADIE: Goals, Assessment, Design, Implementation, and Evaluation, always cycling back to goals throughout the whole process. This design process aimed to mimic the cyclical behavior of ecosystems because ecosystems never operate in a linear fashion, so neither should design.

Map-making was a central part of my project. The maps I made for portraying my design process are a culmination of my knowledge gained from various design classes I have taken at University of Vermont. The professors who taught me the landscape design process and how to render maps effectively include: Stephanie Hurley, Liz Calabrese, David Raphael, Jane Sorenson, and Keith Morris. I learned graphical techniques from Grant Reid's book, *Landscape Graphics* (2002). I created large-scale (24" by 36") base maps with ESRI's GIS (Geographical Information Systems) software to use for tracing.

Objectives

My project objectives included: articulating my goals clearly and concisely, completing a site analysis and assessment, developing conceptual designs for various phases of implementation, creating a schematic design for phase 1, and completing design details that would support the schematic design including planting plans, planting lists, sections, section-elevations, and perspective drawings.

Goals Articulation

To begin, I used David Jacke's (2005) guide to goals articulation in order to conceive clear goals that would direct my design to achieve my true intentions. First, I figured out the functions that I wanted to achieve on the landscape. The permaculture saying "form follows function" is critical when articulating goals because it is often easier to think of the form first and not the root of its function. I wrote down my functional goals in present tense in order to fully realize what my goals would entail. This is a strategy encouraged by Jacke (2005), because it feels more real and carries more presence.

I came up with my design objectives, which are the functions that will increase resiliency on the landscape. Subsequently, I completed a program development to determine forms that would fulfill my desired functions. The program development consists of the design element, its use, size, relationship to other elements, and its character. I also did a niche analysis where I analyzed the needs and yields of each element.

I came up with a long-term plan for implementation, because the design elements would not be realized all at once. Phase planning was essential to visualizing long-term goals for the landscape with regard to practical implementation.

Site Analysis and Assessment

I started my site analysis by researching and evaluating the context of the farm. I did an analysis of the bioregion with information from *Wetland, Woodland, Wildland: A Guide to the Natural Communities of Vermont* (Thompson & Sorenson, 2005), Whole Systems Design LLC's *Teal Farm Master Plan* (2000), and Vermont Department of Forests (2001). I used maps to help portray the bioregional context of the site from Google Earth, Google Maps, and Vermont Interactive Map Viewer.

I looked into the history of the area and the farm because past land uses have a lot of impact on the present condition of the land. The client was the main source of information about historical uses of the land. By understanding past uses of the land, I came to understand why the forests and fields are composed the way they are. An important part of this history is the observed changes in climate and weather conditions from the client.

I began the analysis of the site by delving deeper into the characteristics of the landscape and revealing important patterns and processes occurring on the landscape. I followed the permaculture "scale of permanence" to analyze the site and look for opportunities or constraints. The scale of permanence analyzes site aspects from climate, which is the hardest to affect, to aesthetics and experience of place, which is the easiest to affect. By evaluating a landscape at the various levels of potential human impact, I was able to clearly see where I could have the greatest leverage as the most important problems and opportunities emerged. The scale of permanence is listed in the following from least ability to affect to most ability to affect:

1. Climate (hardiness zone, growing degree days, extremes)
2. Landform (altitude, aspect, slope, erosion, earthworks, bedrock)
3. Water (watershed, runoff, impervious surfaces, rainwater, septic, springs, wells, streams, ponds, erosion)
4. Legal Issues (property lines, setbacks, right-of-ways, permits, zoning)
5. Access and Circulation (routes, sizes of routes, possible access, contextual)
6. Vegetation and Wildlife (plant identification, plant communities, indicators, patterns of distribution, habitats, predators, pests)
7. Microclimate (human scale and up, near bodies of water, wind exposure/protection, sun exposure, frost pockets, wet/dry)
8. Buildings and Infrastructure (location, insulation, heat, hot water, structural integrity, propane tanks, water lines, woodshed)
9. Zones of Use 1-5
10. Soil (sand/silt/loam, slope, fertility)
11. Aesthetics, Experience of Place (views, noise, feelings instilled)

I made various layers for the site analysis to be able to more clearly see the processes going on in the landscape and their relationship to each other. I used various maps and programs to find information about climate, landform, water, and soil. ESRI's GIS software allowed me to assess the elevation changes on the landscape and view the slope aspects (orientation). I downloaded GIS map layers from Vermont Center for Geographic Information's (VCGI) Vermont's Open GeoData Portal including soils and significant ecological communities. To find all the different types of soils and descriptions, I used the Web Soil Survey (USDA NRCS, 2014). In addition, I used a map made by the client's land management company, LandVest, which was very helpful for rendering topographic lines and analyzing forest communities on the land (Hart, 2006).

I analyzed energy sectors on the site, which encompassed external energies such as sunlight, wind, rain, and water flow (Mollison, 2011). These energies come from outside of the Greenleaf Farm system and pass through it. I included a sector analysis as part of my site analysis to determine the potential impacts of these outside energies.

In addition to analyzing natural systems occurring on the site, I also analyzed human systems, including zones of use and circulation patterns. I made a map of the zones of use on the farm. Zoning is determined by the number of times that area is visited. Zone 0 is the center of activity, in this case, the house. Zone 1 is close to the house and visited daily; it is the most controlled and intensively used area. Zone 2 is still intensively maintained but not necessarily visited daily, with dense plantings and can include ponds or hedges. Zone 3 contains pastures or unmanaged orchards. Zone 4 is semi-managed, semi-wild, used for gathering and wildlife and forest management, and is not visited very often. Zone 5 is unmanaged or barely managed natural "wild" systems (Mollison, 2011). I also mapped the common circulation patterns of vehicles, off-road vehicles and tractors, and pedestrians (the client).

I analyzed the various processes occurring on the site and made an assessment map of design opportunities and constraints that would later inform my design decisions. These observations of opportunities and constraints were made with regard to my greater goals for the landscape.

Conceptual Design

During this step of the design process I developed concepts based on the site analysis and assessment. The areas with specific opportunities or constraints often translated into design solutions to address them. This was the step where function flowed into form and I determined the most practical design elements to include.

I created many loose conceptual designs to explore various relationships on the site and determine the best elements to include in my design. These maps consisted of bubble diagrams and circulation patterns. I made a final conceptual diagram with the elements I wanted to include in Phase 1 and the optimal location for greatest multifunctionality and most efficient energy planning. Relationships are the most crucial part of conceptual planning because strategic placement of an element determines whether it can take greatest advantage of surrounding by-products and resources. Bill Mollison (2011) advises that the key to efficient energy planning (or efficient economic planning) is zone planning. Zone planning means placing elements according to how much they are used or how often they need to be serviced.

I created additional conceptual designs to illustrate subsequent phases in design and implementation as well as land management strategies that encompassed the entire property. I made a conceptual design to illustrate a potential future house site and design development from that new center of activity. I also created a conceptual diagram to propose areas of forest, wetland, and streams to be conserved indefinitely to protect ecologically significant areas and allow forests to grow uninterrupted.

Schematic Design

I developed a schematic design, which is a detailed site plan of the final design. I created a schematic plan solely for Phase 1 (Years 1-3) because I could not predict what a detailed design would look like for Phase 2 and 3 since I will be employing adaptive management. Adaptive management entails observing systems after implementation and allowing the lessons learned to shape the next step in design and implementation. Phase 1 includes design elements that can be readily implemented by the client or I and possibly help from family and friends. These elements are mostly in Zone 0, 1 or 2 because they will be regularly used and able to be maintained. I was strategic in picking what design elements to include in order to make it viable to implement soon and allow for growth in future designs.

Detailed Design

I created supporting design visuals and information to better portray my ideas and delve deeper into design details. These design details support the schematic design and include sections, section-elevations, planting plans, and perspective drawings to better inform the audience of what the design would entail. I compiled recommended plant lists along with the planting plans. The plant selections drew from my previous knowledge from classes and working in the field, recommendations from my Professor Jane Sorenson (2013) for landscape design for pollinators, Keith Morris's recommendations for nut trees, and several databases of plants including David Jacke's selections in *Edible Forest Gardens* (2005), Doug Tallamy's top native plants (2007), *The Vermont Rain Garden Manual* (Hulett, 2014), Lady Bird Johnson Wild Flower Center (2014), and Missouri Botanical Garden's plant finder (2014). The detailed design supplements are to better inform the "client" about my design intentions.

Presentation

I produced a professional presentation of my final master plan with design drawings on black foam boards. I included a site analysis and assessment, conceptual designs, schematic design, section views, section-elevation views, perspective drawings, planting plans, and supporting details. I designed the presentation as if I were presenting a master plan to a client in the landscape design field.

Results

The integrative design process was very successful, especially for reflecting back to my goals throughout the whole process. I did not get to the point of implementation for this project because it was beyond the scope of my thesis. However, I did consider the aspects of implementation and maintenance in my design with great care. For example, I found that I had to scale back on the extensive food production systems I had originally imagined because I went back to my goals and realized that the systems were excessive for the current residents and they would not be able to be maintained and did not fulfil definitions of resilience. Resilience thinking led me to practical solutions that made economic sense as well as ecological and agricultural sense.

Goals Articulation

Articulating my goals was arguably the most important step of my design process. I found it invaluable to articulate the functions I most desired from the landscape in order to create the most helpful and relevant forms for my design. Every aspect of my design follows one of these overarching functional goals, stated in present tense:

1. Greenleaf Farm is more diverse and complex and therefore more resilient to increasingly variable weather conditions due to climate change.
2. Greenleaf Farm is an organic, diversified farm that aims to produce a year-round supply of food, fertility, fuel, electricity, and medicinal products for current residents.
3. Greenleaf Farm supports current and future generations and is economically viable and regenerative.

I came up with a list of design objectives (specific functions) that addressed the overarching goals of the landscape, the client, and myself.

Design Objectives (Function):

- Greenleaf Farm (GF) allows wetlands, streams, and a forest block and corridor to be undisturbed by human activity, specifically logging.
- GF provides diverse wildlife habitat with native plantings and landscape patchiness.
- GF diversifies food production with perennial polycultures and other forms of production.
- GF reduces runoff and erosion by slowing, spreading, and sinking water during rain events.
- GF is resistant and resilient to heavy rains, flooding, drought, strong winds, hail, reduced snowpack, extreme temperatures, and overall variable weather conditions.
- GF builds topsoil and increases the health and fertility of the soil.
- GF intervenes in field succession and creates greater diversity with multifunctional species.
- GF creates microclimates on the land suitable for various production and habitat niches.
- GF integrates intensive rotational grazing into its food systems to increase fertility and further diversify resources.
- GF uses on-site resources as much as possible.
- GF maximizes use of renewable energies.
- GF extends the growing season.
- GF meets every essential function with multiple elements.
- GF achieves self-renewing fertility (regeneration) by retaining more nutrients and producing more root mass.
- GF grows its own preventative medicine.
- GF has an ongoing supply of seeded, grafted, and propagated trees, shrubs, vegetables, and herbs.

Site Analysis

The final two site analysis maps can be found on the next page, figure 8 and 9.

History

The alkaline soils of the Northern Vermont Piedmont biophysical region, derived from calcium-rich bedrock, were a factor leading to heavy early agricultural use in the region (Thompson & Sorenson, 2005, p. 46). European settlement of the region began in the mid-1700's with a large influx of settlers in the late-1700's and early-1800's. Deforestation for agriculture and timber increased dramatically around 1800, and

Figure 8. Site Analysis (Scale 1"=150') **Figure 9. Site Analysis (Scale 1"=40')**

approximately 80 percent of Vermont's forests were cleared by 1900.

Scottish settlers were the first people to settle this land in the year 1800. The land was clear-cut from 1840 to the 1920's for sheep. The land has primarily been used for pasture for beef cattle from 1920 to 2003. My parents bought the original piece of land, which is the southern half, in 1977 and built the house in 1978. They used kerosene lights until they installed solar panels in 1990. In 1995 they bought the Vyskup piece of land, which is the northern half and encompasses the top of Lost Mountain.

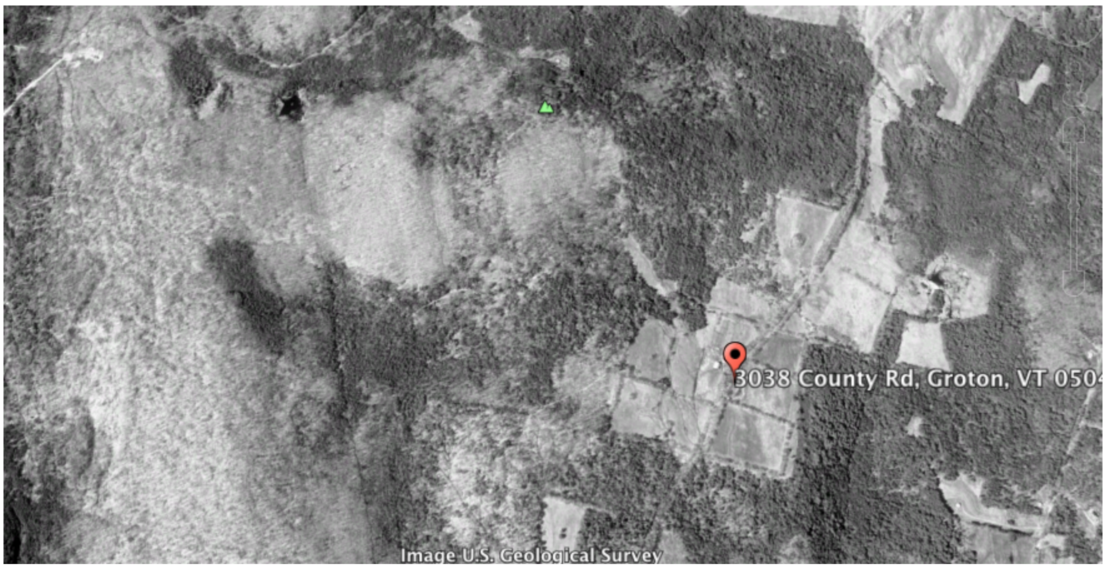

Figure 10. 1992 aerial photograph (Google Earth)

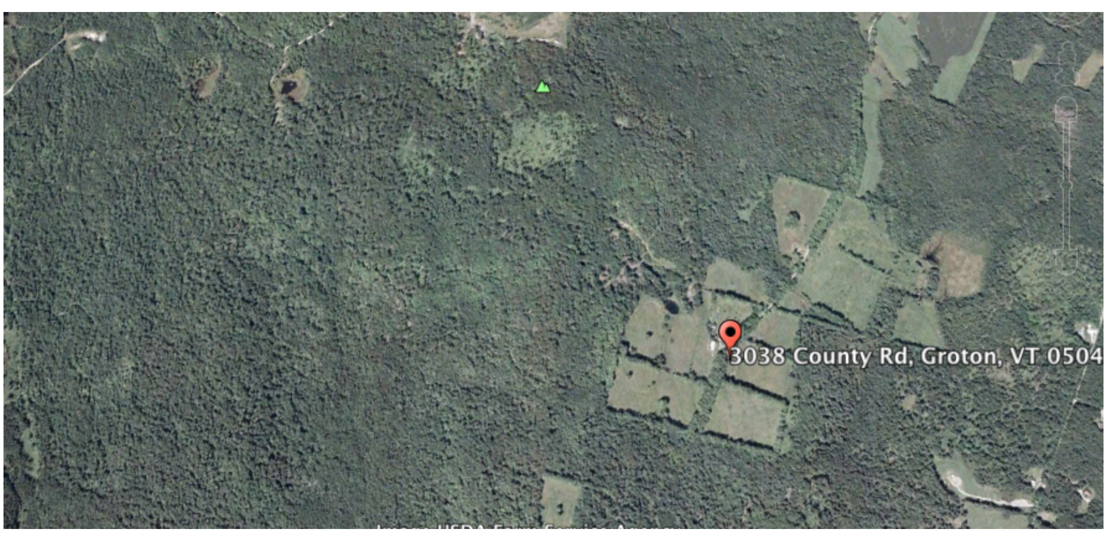

Figure 11. 2003 aerial photograph (Google Earth)

The photos above show the change in succession from 1992 to 2003. The forest has grown in a bit, and there are also some disturbance areas from logging on the northern end near the top of Lost Mountain. The aerial from 1992 clearly depicts the divide between hardwoods and softwoods because it was taken when there were no leaves on the trees. The client stopped farming in 2003 and let most of the fields succeed into forest. The aerial photos below depict the successional stages of the fields from 2003 to 2011. The primary species coming in are white pine, red maple, chokecherry, and juniper.

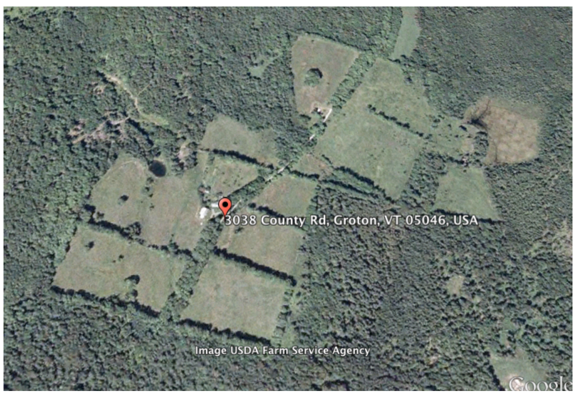

Figure 12. 2003 aerial photo (Google Earth)

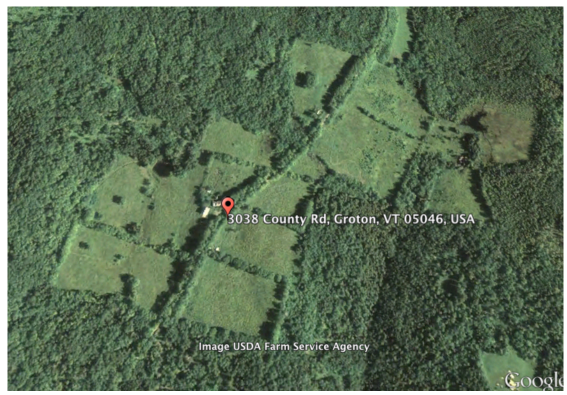

Figure 13. 2006 aerial photo (Google Earth)

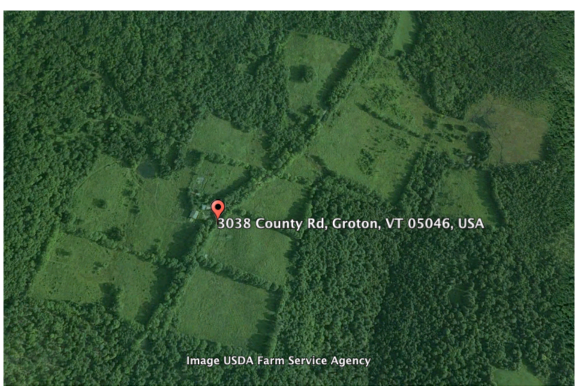

Figure 14. 2009 aerial photo (Google Earth)

Figure 15. 2011 aerial photo (Google Earth)

Energy Sectors

Mapping the sun's path throughout the year helped me to see more clearly how I could take advantage of its energy. The following figure is from the website, *SunCalc*, and depicts the range of sun paths, from summer solstice to winter solstice, with the lines marking the sun path on the equinox.

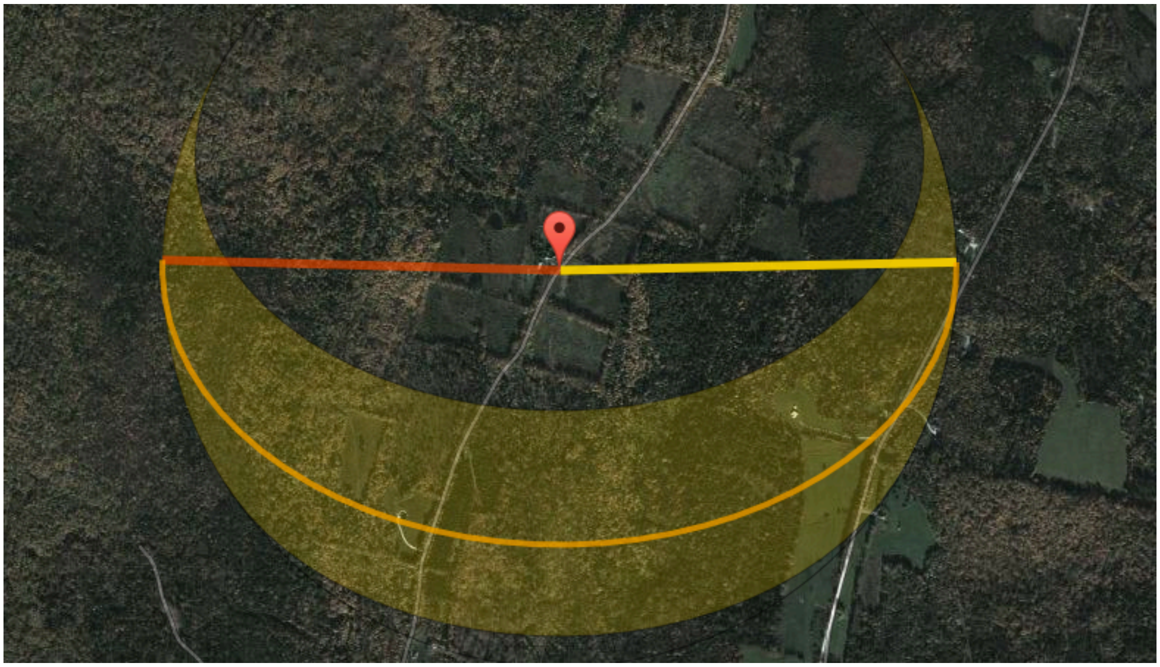

Figure 16. Sun Paths (Agafonkin, 2009)

The prevailing winds on the site come from the southwest and the northwest. The northwest winds are often cold winter winds. The southwest winds are often much warmer. The house is fairly protected from extreme northwest winds because of the hill to the northwest. It is fairly exposed to southwestern winds, which are not as extreme. Water generally flows from north to south.

Climate

The site is technically in Hardiness Zone 3 according to the USDA Hardiness Zone Map (2012), meaning that the average annual extreme minimum temperature is -40°F. However, the client has only seen the lowest annual temperature go below -30°F once since 1977. Essentially, the site is currently in Hardiness Zone 4, meaning that it does not go below -30°F. Nevertheless, it seems to be shifting to Zone 5 due to climate change. Zone 5 requires no colder than -20°F in the winter. The lowest temperature this past winter (2013-2014) was -14°F, making it Hardiness Zone 5 this year. The growing season is 119 days or more, with a first frost-free date of May 30th and a last frost-free date of September 17th (USDA, 2012).

The average annual precipitation has also increased since the client moved to the land. The site used to get about 38 inches of rain a year, observed by the client in the 1970's and 1980's. Now it gets about 45 inches of rain a year, observed from 2003 to 2013, which is an 18.4% increase in the last forty years. This increased rainfall is observed to occur most heavily in the spring and summer. Other observations include less snow in the winter with more thaws, more crusty and icy snow in the winter, and more rain in the winter. On April 15 in the eighties, there was always a lot of snow still on the ground; by the 2000's, that snow is largely gone. The client kept maple sugaring records from 1981 to 2006. In the last 10 years (1996-2006), the last boil was 5 days earlier than the average in the 1980's. There is a shorter sugaring season now of about one month, where it used to be 1.5 to 2 months. These observations line up to researchers discoveries at University of Vermont's Proctor Maple Research Center, and found that throughout the northeast U.S., the maple sugaring season is starting significantly earlier than it did 40 years ago, and the duration has decreased by an average of 10% (Perkins & Wilmot, 2007). The first run has become increasingly sporadic, foreshadowing the increasing variability and unpredictability of future weather conditions.

I made a map layer of how predicted weather conditions may stress or alter the hydrology patterns on the site to better visualize the impact on the landscape (Appendix A). Creating this map layer from NECIA's (2007) weather predictions allowed me to see areas of high stress and risk on the site. The areas of greatest stress were streams and wet areas that would be inundated by heavy precipitation events. Drought and heat spells were also a concern in warm, south-facing microclimates.

Landform

I analyzed various landform characteristics such as bedrock, slopes, and aspect. The site is part of the Connecticut Valley Trough bedrock, resting on the Waits River formation (Ratcliffe et. al., 2011). The Waits River Formation consists of carbonaceous phyllite and limestone. The rock class is defined as metasedimentary from Lower

Devonian and Upper Silurian periods. Metasedimentary means that they originated as sea sediments and underwent intense metamorphism (Thompson, 2005). The carbonate-rich rocks have high concentrations of calcium carbonate and weather easily, releasing calcium and other important plant nutrients (Thompson, 2005). This also helps to neutralize the acidic eastern soils because it is very alkaline or “sweet”. The bedrock crops up in some areas and can generally be found anywhere from 0 to 40 inches below soil surface. There are some pockets where the bedrock is over 80 inches below the soil surface (USDA NRCS, 2013).

The following maps show an elevation hillshade and topography to depict the changes in elevations and slopes on the land.

Figure 17. Contour map (Google Maps)

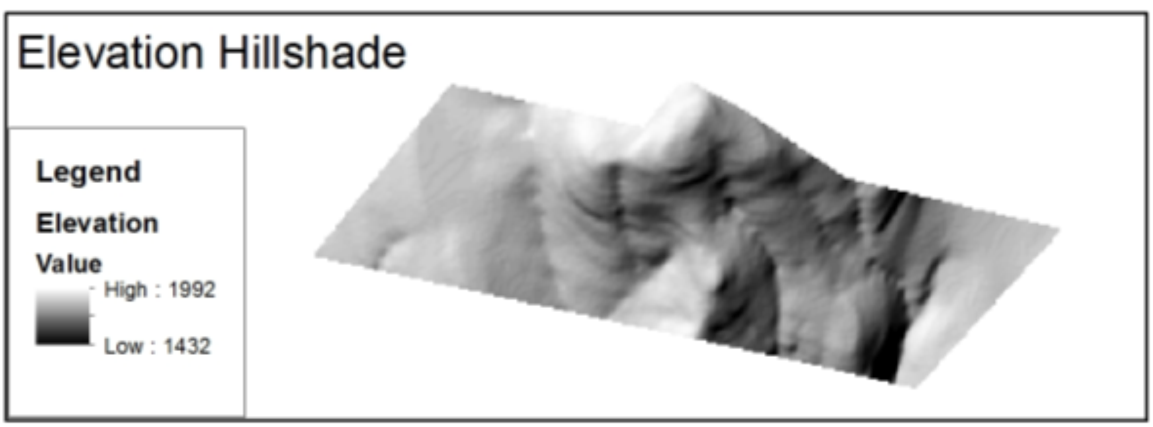

Figure 18. Elevation hillshade (ESRI's ArcGIS, 2013)

The following image was rendered using ESRI's ArcGIS (Geographic Information Systems (2013) to show major aspects on the site.

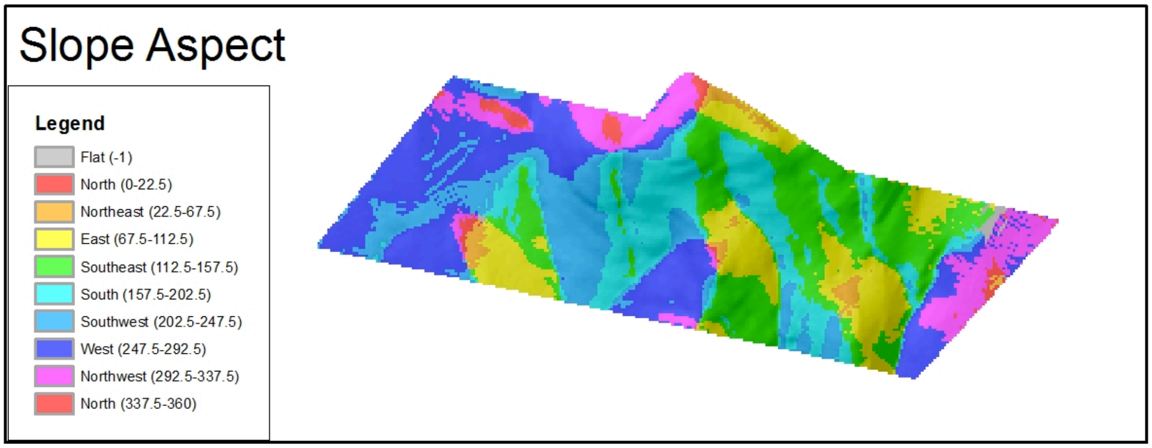

Figure 19. Slope Aspect (ESRI's ArcGIS, 2013)

The dominant aspects of the house site and fields are east, southeast, and south, allowing for early morning sunshine and warm southern sun exposures to reach these areas. There is also a significant northeast facing area near the house, which can be ideal for fruit trees because the sap does not rise too early in the spring due to southern exposures and cause sunscald (splitting of the bark). Site analysis maps of topography, slope, and bedrock can be found in appendices B, D, H, I, J, and figure 20 on the next page. Creating the maps with topography lines, slope lines, and areas of bedrock outcropping allowed me to understand the lay of the land much more deeply. The sight is very hilly with nuanced slopes that do not show up in the 20-foot topography lines. The relationship between bedrock and ground surface emerges, with bedrock close to the surface at hilltops and very deep beneath the surface in depressions. Overall, the bedrock is relatively close to the soil at such high elevations.

Water

The Greenleaf Property is a fairly wet site. Site analysis maps of water, hydrology, and drainage can be found in appendices B, D, H, I, J, and figure 20 on the next page. The site contains wetlands, streams, and ponds that flow into Red Brook and the Northern Branch of Wells River. There are seven springs on the property, all of which

Figure 20. Site Analysis: Topography, Water, Forest Type (Scale 1"=416.7')

are lying between the elevations of 1600' and 1760'. It seems to be a very wet area in that belt of the property, which must mean that an aquifer meets the ground surface. Three of the springs have been developed and built up around with concrete wells. Two of the springs can be gravity-fed to the old house site on the Vyskup piece of land (northern half of property) and are reliable. Only one spring is currently in use and functions as the main water source for the house and is very reliable. The biggest spring is in the southwest corner of the property and has never dried up.

Figure 21. Photos of one of the springs

There are three wetlands on the property, two in the northwest corner and one large swamp in the northeast corner. There is a man-made pond above the house with a stream running through it; it often fills up with silt in heavy precipitation events. The house has a septic tank and leach field in the back yard. There is also a well for backup water supply in the backyard. This well was used before the waterline of PVC piping was built from the spring to the house. The main spring has only gone dry once since 1977. An underground stream runs under the vegetable garden, well, and corner of the house addition, most likely coming from the area where the aquifer meets the ground surface. There is a system of five perforated drainage pipes in ditches of gravel under the garden to help alleviate flooding and saturation. The house addition basement experiences flooding from time to time, but it has a dirt floor and is not used for anything.

I found that many of the fields were fairly well drained at high points and on the slopes with areas of depressions that tend to get very wet. Early settlers installed drainage tiles in several of the fields consisting of ditches filled with gravel and stone. Overall, the landscape is quite wet and there is vary rarely shortage of water. The site is much more vulnerable to flooding and saturation than drought.

Legal Issues

There is a 50-foot right-of-way (ROW) zoning law for the road. However, the client received a variance to build the bucket house for maple sugaring, which is about 20 feet from the road. The Town of Peacham is fairly lenient with zoning laws. This is helpful to know if I want to build anything close to the road (for example, a farmstand).

Access and Circulation

County Road is a class 4 dirt road that runs through the land. The house sits close to the road on a throughway driveway. There is a parking lot and turnaround at the southern end of the driveway and just south of the property line (also the town line). The road is a dead end in the winter because Peacham only plows to the town line. Every field has a gate and can be accessed with a vehicle. The main access to the back of the land is a trail that connects to the snowmobile trail that is maintained by the Vermont Association of Snow Travelers (VAST). This trail is mainly for walking, all terrain vehicles (ATV's), snowmobiles, and tractors. A truck with high clearance could also drive on the trail and snowmobile trail if necessary. The snowmobile trail leads to the State Road in Groton State Forest, with two other access points at the northwest corner of the land. There are also remnants of various logging roads that may or may not be currently accessible, depending on downed trees and young saplings. See figure 22 on the next page for access and circulation; access to the entire property can be seen in figure 20.

Figure 22. Site Analysis: Zones of Use, Access & Circulation (Scale 1"=40')

Vegetation and Wildlife

The basic tendency of the land is to grow trees—lots of trees. Figure 20 illustrates the various forest types. The client described four main sites that categorize the natural communities on the land. Site 1 contains excellent hardwood including sugar maple, beech, white ash, basswood, and yellow birch. Site 2 is a mix of hardwood and softwood and contains red maple, sugar maple, white pine, red pine, red spruce, white spruce, balsam fir, white birch, yellow birch, white ash, black cherry, and some hemlocks. Site 3 is primarily softwood and contains tamarack, cedar, dogwood, and softwood on hummocks. Site 4 is in the marshy areas surrounding the wetlands, comprised primarily of white cedar.

The Northern Hardwood Forest Formation makes a transition to Spruce-Fir-Northern Hardwood Forest Formation in colder areas (Thompson & Sorenson, 2005). The shrub layer often consists of striped maple, hobblebush, and shadbush. Herbs and wildflowers include intermediate wood fern, christmas fern, sarsaparilla, painted trillium, spring beauty, false solomon's seal, wild leeks, dutchman's breeches, and trout lily. The understory is often long-lived perennials that store much of their food in their roots, tubers, and bulbs due to the shady canopy (Thompson & Sorenson, 2005).

The site analysis vegetation map layer can be found in appendix F. The three fields east of the road on the original piece of land were bush-hogged around 2006. The two fields east of the road on the Vyskup part of the land were bush-hogged around 2004. In the hay fields there is orchard grass, which likes a lower pH, and reed canary grass and nut sedge in wet areas. Reed canary grass is not desirable because it is invasive and is not good for foraging. Nut sedge is also not good for foraging and both types of grass are very hard to remove. There are stands of poplar colonizing areas on the edge of several fields in wet areas. Maples and softwoods are moving in on the hay fields, primarily red maple and white pine. The hay field where the old Vyskup house site used to be the most productive hay field. Timothy grass and Brome grass grow there. The fields that have not been cut for about 10 years are now intermediate successional communities. The fields to the east of County Road on the Vyskup side contain a lot of ash, white pine, and chokecherry, which is a pioneer and makes way for black cherry. In the fields above the house there is white spruce, red spruce, balsam fir, white pine, and low-bush juniper in poor sites. There is also a lot of blackberry, raspberry, and hardhack, which are all pioneer species. An old field that has now completely grown up with trees is composed of white birch, spruce, fir, tamarack, pine, and red and sugar maples. In wet areas near the garden and streams are reed canary grass, nut sedge, hardhack, red osier dogwood, and ample amounts of mint, which is an opportunist plant.

Figure 23. View from field above house, succession occurring, white pine pioneer

There is an existing windbreak to the northwest of the house comprised of black locust, chokecherry, buartnut (butternut and heartnut hybrid), and red oaks that the client planted. The client also planted black locust up on the hill, which has colonized. Surrounding the house are elderberries, hazelnuts, overgrown grape vines, rhubarb, hops, and comfrey on the bank by the driveway. In the island between the driveway and road are sugar maples, mountain ash, currants, elderberries, and comfrey.

The existing orchard contains apples, pears, and plums. Apple varieties include Honey Crisp, Wolf River, Wealthy, Sweet Sixteen, Prairie Spy, Cortland, Empire, Honey Gold, and Golden Russet. Pear varieties include Patten, Bosc, Seckel, Kiefer, and Nova. Plum varieties include Mt. Royal, Dropmore, Toka, Kaga, Waneta, and Tecumsah. Most have been planted in the last decade, but the client planted several in 1985. Some fruit trees that were planted died from various causes. The apple borer killed a Havalson apple tree, carpenter ants killed two Montmorency cherry trees, and winter killed a Manchurian apricot tree and a Warden grape vine.

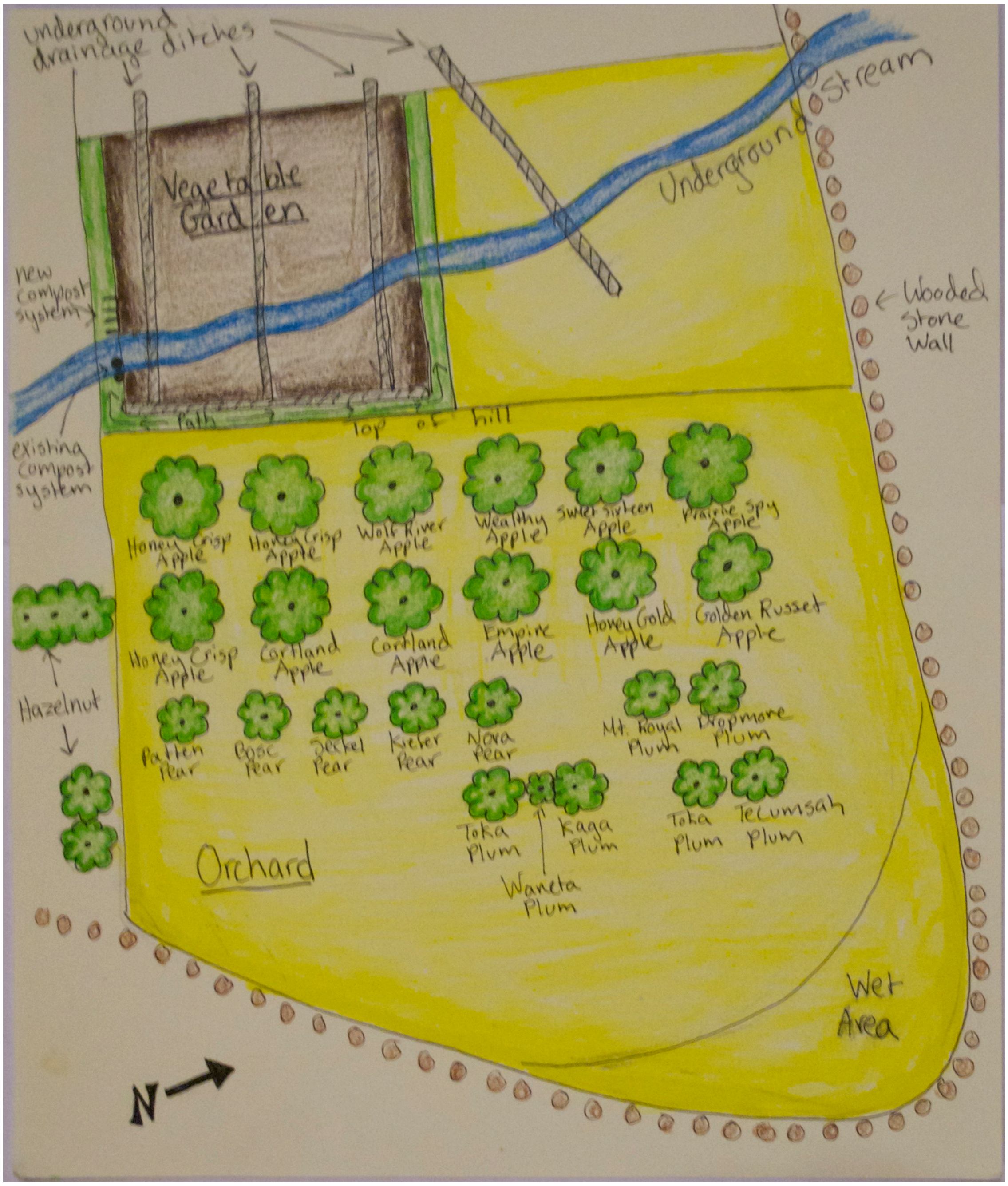

Figure 24. Detail Drawing of Orchard and Vegetable Garden

Figure 25. Photos of orchard in the spring

The apple borer is deadly and attacks after sunscald. Currently, my father paints the trunks with indoor latex and joint compound white paint, installs wire mesh around the base and occasionally uses a topical insecticide called Spectracide (active ingredient: Gamma-Cyhalothrin). Carpenter ants are another problem with fruit trees but can be fairly easily defended against with white paint on the trunks. Other pests and pathogens on the site include grape fungus, and beech blight. The ash borer has not made it this far north yet, but is a serious threat.

There are many pests to compete with in the vegetable garden. Woodchucks love cole crops, while rabbits munch on lettuce and peas. Deer eat everything except the potatoes and peas. In addition, there are the ceaseless potato beetles, cabbage moths, and cucumber beetles. Red squirrels almost always get to the hazelnuts before people do. Bears are an issue with honeybee hives. The chickens also have many predators including weasels, raccoons, and skunks. In addition to pests and predators, there are many weeds in the garden, the worst being galinsoga (*G. quadriradiata*).

Although many animals are pests in the garden, they are essential for healthy ecosystem functioning in this biophysical region. Large expanses of intact forest are critical for many animal species. Characteristic wildlife of Northern Hardwood Forests are the masked shrew, eastern cottontail, red squirrel, southern flying squirrel, white-footed mouse, woodland jumping mouse, chipmunk, porcupine, black bear, and white-tailed deer. Characteristic birds are the hermit thrush, rose-breasted grosbeak, oven bird, red-eyed vireo, eastern wood pewee, black and white warbler, black-throated blue warbler, veery, and scarlet tanager. Northern Hardwood Forests provide habitat for many salamanders, including the redback salamander, spotted salamander, and eastern newt. Wood frogs and redbelly snakes thrive as well (Thompson & Sorenson, 2005).

Buildings and Infrastructure

The existing buildings include the house, woodshed, barn, garden shed, equipment shed, sugaring house, and bucket house. The client built the house in 1977 and 1978. It is heated with wood and powered with solar electricity. The main water source is a gravity-fed spring. The house contains an addition with a flushing toilet, a pantry that stays cool, a basement with a workshop, and a root cellar. The woodshed is attached to the house and contains an outhouse. The original settlers on the land built the barn in 1820 and hand hewn all the beams. The barn houses the chickens and is currently used mostly for storage. In the past it has housed goats, cattle, and hay.

Figure 26. Photo of house from the south and solar panels, wood shed is to the right

Figure 27. Photo of the barn from the east with chicken yard in front

Zones of Use

I created a map of existing zones of use where I analyzed the routes my father takes and how often he visits areas of the farm. Zone 0 consists of the house and woodshed. Zone 1 includes the yard, the area in the barn where the chickens live, and the compost and garden. Zone 2 includes the rest of the barn, the orchard, and the pond. Zone 3 includes the fields and the springs. Zone 4 includes of the rest of the land, consisting mostly of forest because it is a managed tree farm. There isn't really a Zone 5 on the site because nothing is left completely wild; the forests are continuously being managed for timber. See figure 22 for the site analysis of zones of use and circulation routes.

Soil

See figure 28 below for the soil map and descriptions. The complete table of soil descriptions can be found in appendix C. Other site analysis maps of soil can be found in appendices E and I. Sandy loams dominate the soil types on the land, a product of glacial

Figure 28. Site Analysis: Soils (Scale 1"=400')

till. The land is very rocky in areas, but the first settlers cleared the fields of rocks and built the stonewalls with them. Sandy and stony soils are a product of glacial outwash (Thompson &Sorenson, 2005). The fine sandy loams and very fine sandy loams allow high water drainage. There are some areas comprised of silt loams and mucks that do not drain well and tend to be much wetter. Dummerston very fine sandy loam offers the best agricultural land, and is found around the house site, and much of the fields. Very fine sandy loam, fine sandy loam, and sandy loam tend to support the hardwood forests. Softwoods and mixed forests are mostly found on the loams and silt loams. The wettest areas on the site are found on silt loams and mucks.

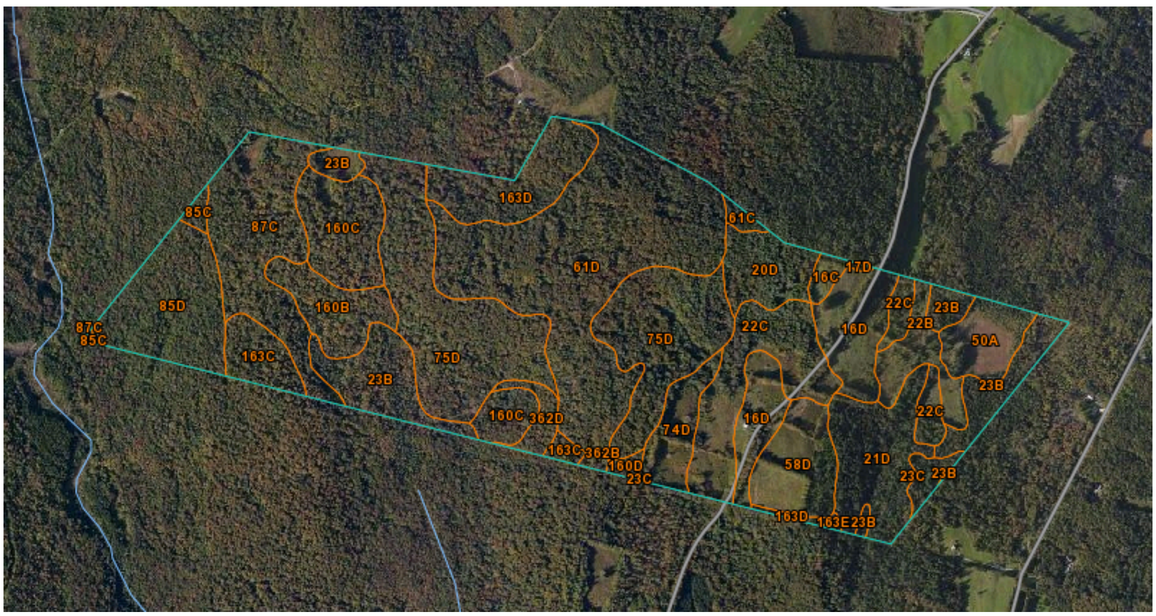

Figure 29. Soil Map (USDA NRCS, 2014)

There is a layer of clay below the subsoil that holds moisture well. In the client's experience, the topsoil is typically 6 to 8 inches deep; the subsoil below is 10 to 12 inches deep, and then a 3 inch layer of gray clay beneath that. Below the clay is a layer of poor subsoil on top of the bedrock. The bedrock changes in depth and undulates underneath the soil. The soil is fairly acidic even though it lies on calcium-carbonate rich bedrock. The average pH of the soil in the garden is 5.5, which is slightly acidic.

The only area of major erosion is along the stream banks in the softwoods of the southeast corner of the property. This is due to logging that occurred upstream several years ago, altering the stream dynamics and flow.

Current additions to the soil for agricultural purposes include chicken manure (nitrogen), bone char (phosphorus), wood ashes (potassium, alkalizes soil), and compost (mainly grass clippings and food scraps). The client also spreads urine the orchard for nitrogen.

Figure 30. Compost system, frame of the 3 bin system I built last year in the back

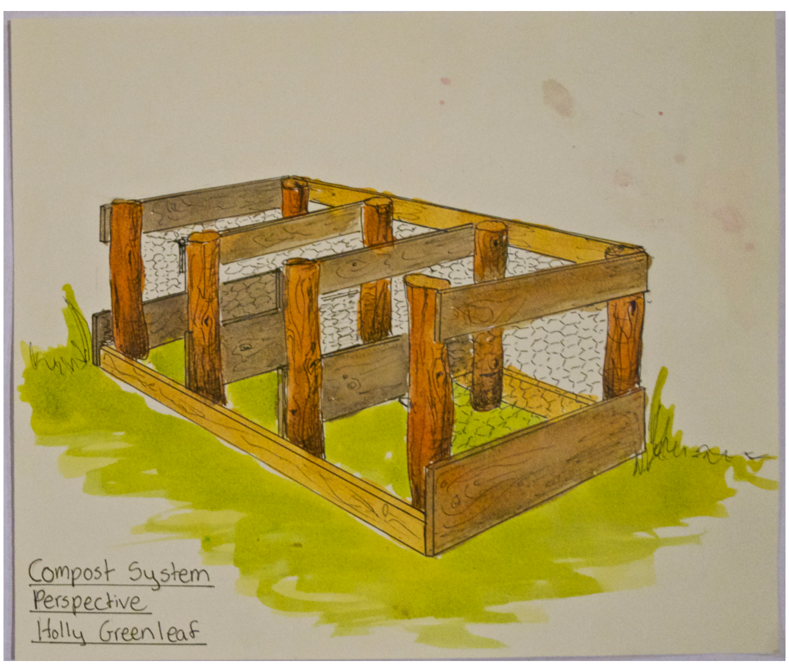

Figure 31. Design for 3-bin compost system I built (2013)

Experience of Place

The sense of place instilled when visiting Greenleaf Farm brings you back to the old days of Vermont farming. The feeling is rustic and rugged yet homey and comforting with the patchwork of fields and forests lain over the low rolling hills. County Road is rarely travelled, but picks up around hunting season. The farm is very secluded, especially in the winter when the road turns into a dead end. The bucolic farm feels protected, nestled in the undulating fields and wooded stonewalls, surrounded by forest. As soon as you get up on the hill surrounding the homestead, you start to catch site of the surrounding mountains. From the hill above the pond, the view to the east is breathtaking; Blue Mountain rises in the foreground, and on a clear day you can see all the way to the white peaks of Mount Washington and Lafayette in New Hampshire.

Figure 32. View from driveway across the road to sugar maple field borders

Figure 33. View from the hill looking southeast, Blue Mountain begins to rise to the left

Discussion

The site analysis process facilitated my discovery of the unique processes and patterns occurring on the Greenleaf Farm landscape. Analyzing the various map layers revealed a dynamic interplay between bedrock, soils, water, vegetation, sun, wind, and people. Additionally, by evaluating climate impact and energy sectors flowing onto the land, I realized how deeply connected and embedded the site is to the greater bioregion and the rest of the world. Thus, how I choose to manage Greenleaf Farm can have a rippling effect on the surrounding landscape. I found that there were many ecologically significant areas on the site. Wetlands are important environments because they are nature's water filtration systems and provide important wildlife habitat. The biggest wetland on the site is the headwaters for the North Branch of the Wells River. The health of that area has a cascading effect on the health of the subsequent Wells River watershed. There are also many springs, evidently coming from an aquifer. Protecting the quality of the water flowing from these clean, freshwater springs is vital. These areas of the site should be protected from harmful human activity, including logging.

After analyzing potential future climate impacts, it became clear that the landscape could benefit from a more even distribution and infiltration of water into the ground with systems such as ponds, swales, paddies, or keyline ditches. There is also ample opportunity to take advantage of wet areas to grow wet-loving species such as rice or cranberries. The soil is not very deep in many areas, making topsoil creation a top priority in the landscape. Building topsoil will help with regulating water extremes of flooding and drought and will increase the fertility and vegetative capacity of the land.

Site Assessment

Assessing the natural processes occurring on the landscape allowed me to see potential opportunities and constraints for design solutions within the context of my greater goals for production and resiliency.

Figure 34. Site Assessment (Scale 1"=150')

Figure 35. Site Assessment (Scale 1"=40')

At the field-scale, I summarized the characteristics of each field concerning soils, slopes, sun exposures, and drainage. I found that some of the best productive land was surrounding the old house site on the Vyskup piece of land (northern fields). It is comprised of very fine sandy loam with southeast exposure, maximizing morning and southern sun. The fields across from the current house are either very wet or close to bedrock. The fields south of the barn and north of the orchard are also good agricultural land to expand to production to. At the homestead scale, I mainly assessed the microclimates in Zones 1 through 3 because those are the areas of greatest activity and management opportunities. Hedgerows and buildings created warm southern microclimates with protection from cold northwest winds. The front yard is a great south-facing microclimate in Zone 1 that is walked by every day. However, the topsoil is not very good due to construction of the house. The area to the south of the garden shed is a sunny microclimate with good wind protection to the northwest. The existing trees in the orchard are widely spaced and provide opportunities to integrate micro forest gardens. Wet areas can be seen as opportunities or constraints. The field right next to the garden is very wet but in a strategic place, near existing systems. The field below the pond is very wet because muskrat dig holes in the bank, which should be addressed. The pond also fills up with silt from the stream running into it. The silt is an opportunity for an on-site source of soil-building materials.

Many of the fields around the house have southeast exposure and are well drained with fine sandy loams. The field just to the south of the barn has a very promising microclimate with ample southern sun exposure, good drainage, and likely good fertility from years of cow manure, due to high cattle concentration in the area. There are some shady areas on the north side of the house and barn. The septic system and leach field pose constraints for the backyard.

There are opportunities for more efficient use and greater use of renewables in the buildings. Passive solar energy could be taken advantage of more with the installation of solar hot water. Currently the water is heated with propane but could be heated by solar hot water and a woodstove in the winter. The house and its occupants could benefit from newer, more efficient windows and insulation. It could also greatly benefit from a greenhouse attached to the south side to maximize solar heat in the winter, yet remain cool in the summer with good ventilation. The outhouse in the woodshed provides opportunity for an easy switch to composting toilets in the summer. The root cellar provides excellent storage space for root vegetables and canned foods. Food storage, processing, and preservation are important for food resiliency in Vermont's long, cold winters. Use of the workshop in the basement could be made more enjoyable if it was moved to a sunnier location with more square feet, but still close to the house for easy access.

Conceptual Design

The opportunities and constraints discovered in the site assessment led me to conceive design solutions (forms) that addressed the desired functions I came up with in my goals articulation. I completed a program development for each design objective with an emphasis on its niche (needs and yields) in the system and relationships to other elements.

Program Development (Forms)

- Native species plantings in old pastures and the seasonal stream (wildlife habitat, meadow restoration, water filtration)
- Conservation of a block of forest, forest corridor, and wetland and stream ecosystems (protection of ecologically important landscape features)
- Hoop house, greenhouse, high and low tunnels, cold frame (season extension)
- Ponds, swales, paddies, terraces, keyline design (reduces runoff and erosion, provides irrigation and replenishment of groundwater, ameliorates effects of heavy precipitation events)
- Edible forest gardens (perennial polyculture to diversify food production, increases soil health, regenerative, retains and cycles more nutrients, produces more root mass)
- Windbreaks/shelterbelts/snow fence (wind protection, wildlife corridors and habitat, creation of microclimates)
- Nursery/seedbank space and infrastructure (provide supply of seeded and grafted trees, shrubs, vegetables and herbs)
- Compost power mound (provides passive heat for greenhouse, creates finished compost)

- Solar hot water and restore wood-heated hot water system (maximizes use of renewable energies and minimizes dependence on fossil fuels)
- Composting toilets (diverts waste from septic system and creates finished compost, builds soil fertility and closes loop between humans and food)
- Hugelkultur (creates wildlife and pollinator habitat, provides fertile mounds for growing)
- Biochar, compost, effective microorganisms (utilizes on-site fertility sources, increases nutrient balance and soil health)
- Native bee nesting and pollinator gardens (provides food and foraging for pollinators with constant overlapping blooming times all season long)
- Honeybees (diversifies food production with honey and also increases pollinator services for crops)
- Cover crops, no-till or reduced-till systems, companion planting and rotational planting in vegetable garden (reduces bare soil and erosion, increases soil fertility and healthy structure, creates habitat for beneficial species)

I soon realized that these were lofty goals for the short-term and would take many years to be fully realized. As a result, I came up with several phases for design implementation along a viable timeline. The following are my goals for each phase, stated in present tense:

Phase 1: Year 1-3

- My father is able to maintain systems when I am gone.
- I am implementing the following systems with help from family and friends.
- I am beekeeping and potentially making honey.
- I am planting fruit and nut trees provided by Elmore Roots Nursery from a work exchange.
- The season is extended with a hoop house, low tunnels, and a cold frame.
- There is a compost power mound to heat the hoop house.
- There are intensive raised-bed gardens in the front yard.
- There is the start of a food forest integrated into the existing orchard.
- There is a catchment pond above the existing pond for silt.
- There are understory plantings of multifunctional desirable species in the successional fields.
- There is a fertigated rice paddy and cranberry bog system.

- There are native grasses, shrubs, and ferns planted in the seasonal stream to filter water from the rice paddies and cranberry bog and provide wildlife habitat.
- A swale is dug and planted with medicinal fruit, berries, nuts, and other edibles.
- On-site fertility sources are expanded with biomass compost, biochar, and wild microorganisms.
- There is mushroom production on logs.
- There is wine grape production.
- There is beer brewing and wine-making with on-site hops and grapes, respectively.
- There is a chicken tractor to rotate chicken grazing around the orchard.
- There is a new vegetable garden site with reduced flood risk.
- There is a rainwater catchment system on the barn to provide irrigation for the new garden and water for chickens and potential future livestock.
- There is hazelnut and Siberian pea shrub planted in the chicken yard.
- There is a native pollinator and edible garden and honeybee hives and native bee houses.
- There is a windbreak to block cold northwestern winds from the new garden site.
- The outhouse is revamped to function as a composting toilet.
- There is an herb spiral in the back yard right outside of the kitchen door.
- There are hugelkultur mounds started near the house and barn for soil-building and wildlife habitat.
- Cover crops, reduced-till, no-till, companion planting, and rotational planting schemes are implemented in the vegetable garden.

Phase 2: Year 4-10

- There are more swales and keyline ditches dug and planted with perennial polycultures.
- There are more forest gardens established.
- The rice and cranberry production are expanded.
- There is solar-hot water and wood-heated hot water.

- There is a greenhouse attached to the south side of the house.
- There is a rainwater collection system on the house and/or garden shed with rain barrels.
- There is a green roof on the garden shed.

Phase 3: Year 11-20

- Forest gardens are well established and regenerative.
- There is an established nursery for native and adapted trees, shrubs, grasses, ferns, groundcovers, vines, vegetables, and herbs.
- There is medicinal food production with herbal plant cultivation and an apothecary.
- There is year-round crop growing with a greenhouse, hoop house, and low and high tunnels.
- There is livestock with intensive rotational grazing schemes throughout systems.
- There is a tool shop addition to the barn for woodworking and metalworking.

Once I had an idea of the design elements I wanted to include in phase 1, I created many concept layers, exploring the different relationships between elements and zones of use, which can be viewed in appendices K and L. The final concept diagram is on the following page, figure It was important to think about the relationship of a design element to the natural processes that would affect it, to people's interactions with it, and to other design elements to maximize energy efficiency. For phase 1, I concentrated all of the design elements in Zone 0, 1, 2, and some areas of Zone 3. It is important to establish systems closest to the house so they can be interacted with regularly, improving ability to observe, manage, and develop well. For example, I thought that the front yard could be utilized because it is so close to the house and is a warm, sunny location. The long-term design might include a greenhouse attached to the front of the house to maximize solar energy use. For the short-term, raised beds would be a good solution because there needs to be smaller, more intensive gardens much closer to the kitchen for herbs, vegetables, and flowers. This also accounts for the poor topsoil by building up the soil on top of it. In

Figure 36. Concept Diagram (Scale 1"=40')

addition, chicken manure and compost are conveniently located nearby for fertilizer. Raised beds would also be short enough not to block the solar panel's sun exposure.

I created an additional conceptual diagram for developing the other house site, close to where the old Vyskup house used to be. This conceptual diagram functioned more as a proposed zones of use map because it would not make sense to establish systems when a house is not there yet. I felt that this was an important element to add because if my sister of I decided to move back to the land for good, an additional house would most likely be in the design plan.

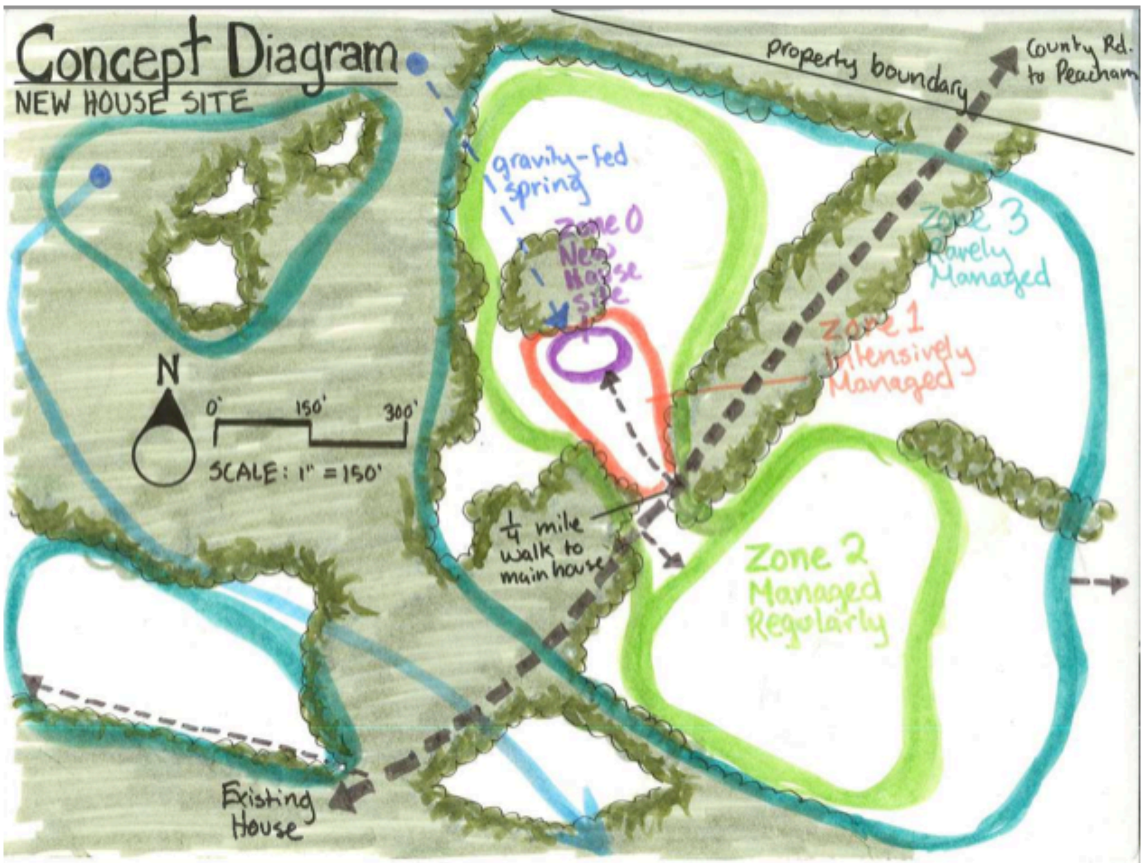

Figure 37. Concept Diagram: New House Site (Scale 1"=150')

I created a conceptual conservation plan for the Greenleaf property, shown below in figure 38. I chose an area of forest to conserve and protect from any future logging or development. This block of forest is valuable hardwood forest on Dixfield sandy loam soil. The site contains the largest spring on the property and is a beautiful area. I chose this area to allow the forest to grow into an old growth forest in the long run. It borders

Figure 38. Concept Plan: Conservation

Groton State Forest and the water running off of it flows into Red Brook. I also want to conserve the three wetlands because they are ecologically significant sites and serve important functions, such as filtering water. In addition, I wanted

Schematic Design

Rendering the schematic design helped me to develop a detailed understanding of what Phase 1 would entail. I determined specific design elements to include in particular locations and how they related to each other, natural processes, and people. The schematic can be found on the next page, figure 39. The following is the program development process I completed in order to understand each design element in the context of the whole system. It includes the human or ecological use, size, relationship to other elements and people, its character, and a niche analysis of its needs and yields. Some categories overlapped but made for an extensive evaluation of each element in the landscape.

Element: Swales
Use: Slow, spread and sink water, capture nutrients, provide passive irrigation, increase groundwater infiltration, replenish aquifers, reduce runoff and erosion, resistance to flooding
Size: 80’ to 160’
Relationship: On contour, below new vegetable garden site and below cranberry bog and pond, close to house and original garden, provides increased surface area and edge effect for diverse species to establish
Character: Experimental, shrub layer and understory layer, edible berries, nuts, vegetables, and herbs
Needs: Establishment (human labor or machines)
Yields: Soil fertility, nutritious and medicinal foods, irrigation, increased groundwater

Element: Microforest garden/tree guild
Use: Produces food, medicinal herbs, increases root mass, maximizes water infiltration, builds healthy soil communities with dynamic accumulators and nitrogen fixers, provides pollinator services, can resist pests with aromatic pest confusers, and provides habitat
Size: Start with 30’ circle
Relationship: Grown around mature tree in orchard or in understory of successional fields, maximizes solar energy with orientation to sun
Character: Mimicking northern woodlands ecosystem structure with three layers—canopy, shrubs, and understory herb layer

Figure 39. Schematic (Scale 1"=40')

Needs: Initial establishment, pruning, harvesting
Yields: Fruit, berries, nuts, edible roots and shoots, greens, herbs, medicinals, organic matter

Element: Windbreak
Use: Protect crops/future livestock from wind, create microclimates, provide wildlife habitat and connectivity, produce food
Size: 120' x 40'
Relationship: On northwest side of new vegetable garden site and swale to protect against cold northwest prevailing winds
Character: Tall, dense, mix of deciduous and evergreens trees, nut and fruit trees, shrubs
Needs: Establishment
Yields: Protection, Wildlife habitat, food for people and wildlife, microclimates

Element: Biointensive raised beds
Use: Kitchen garden of vegetables, herbs, and flowers
Size: 4' x 6' for each bed
Relationship: Close to kitchen, south side of house, takes advantage of warm microclimate, does not block solar panel exposure
Character: Rich soil with high amounts organic matter, lush, dense
Needs: Irrigation, weeding, planting, harvesting, fertilizer applications
Yields: Herbs, vegetables, cut flowers, seeds, joy, beauty

Element: Hoop house, low tunnels
Use: Extend season, provide year-round food production, provide space for starters
Size: Hoop house- 12' x 24'
Relationship: In vegetable garden, north-south orientation for summer production
Character: Foundation made of cedar logs, PVC arches, plastic covering
Needs: Sun, possibly an alternative source of heat (compost power)
Yields: Extended food production, warmer microclimate, protection

Element: Compost power mound
Use: Provides heat for hoop house, alternative hot water source, creates finished compost at end of cycle
Size: ~22' diameter x ~ 5 to 6' height
Relationship: Close to hoop house and electricity source for pump (mini solar?)
Character: Large mound of shredded bark mulch or a mix of woodchips, sawdust, and/or manure surrounded by another layer of woodchips or loose hay for insulation
Needs: Shredded bark mulch, small woodchips, sawdust, manure, hay, spool of high pressure poly piping, pump, compost thermometer
Yields: Heat transferred by hot water to soil beds, season extension, finished compost (compostpower.org, 2010)

Element: Solar hot water/Wood-heated hot water

Use: Provides hot water to the house from renewable solar energy, wood stove for backup heating in winter
Size: 1 square foot of collector for 1.5 gallons of tank capacity (Chiras, 2011)
Relationship: On south facing side of roof
Character: Energy efficiency! Using less hot water and cooler temperatures to reduce pressure on system
Needs: Implementation of new system
Yields: Hot water

Element: Composting toilets
Use: Capture humanure for nutrients
Size: Existing outhouse ~ 4' x 4'
Relationship: Reduce use of septic system, which reduces maintenance costs of septic, very close to house, closes the cycle between food → people → compost and humanure → soil → food!
Character: Rustic
Needs: Maintenance, cleaning out when full
Yields: Finished compost

Element: Rotational grazing of chickens and future livestock
Use: Pest control and food for chicken, weed suppression, soil tillage, nutrients from manure, shelter for chicken under trees, mows grass for easier harvesting
Size: Chicken tractor: about 4 square feet per chicken
Relationship: Quick rotations around various areas of food production
Character: Chicken tractor with easily movable fence
Needs: Intensive management
Yields: Building regeneration, chicken feed

Element: Hugelkultur
Use: Provide fertile mound to plant after the wood breaks down, bumblebee habitat
Size: Long mounds ~ 15' x 5'
Relationship: Close to house, seeded with phacelia and buckwheat (bee friendly)
Character: Old logs and sticks with compost and manure on top, turns into raised beds (mounds)
Needs: Old logs, manure, compost
Yields: Fertile bed for growing

Element: Biochar, biomass compost, effective microorganisms
Use: Build topsoil, build soil fertility and nutrient balance, acts as slow release fertilizer
Size: N/A
Relationship: Provides on-site fertilizer to build topsoil and soil fertility, negating need for external inputs
Character: Biochar—in wood stove or old oil drum, compost—3 bin system for multiple stages of decomposition, wild microorganisms—found in forest and mixed in recipe in 5 gallon bucket
Needs: Management

Yields: Rich, fertile soil teeming with life!

Element: Native bee nesting
Use: Provide habitat for vital native bees
Size: Variable
Relationship: Bring pollinators closer to flowering crops, support native bee species
Character: wooden boxes with drilled holes or phragmites grass, open sandy areas, old piles of wood, dead tree stands
Needs: Construction
Yields: More native bees!

Element: Pollinator Garden
Use: Provide constant overlapping blooming times all season long to support pollinator foraging needs
Size: About 80' x 60'
Relationship: In sunny microclimate south of the garden shed, protected by windbreak to the northwest, honey beehives in garden
Character: Beautiful, colourful, dense, woodies and herbaceous perennials, mainly yellows, purples, and white to attract native bees specifically, bee haven!
Needs: Soil amendments, planting, weeding, irrigation for establishment, pruning and cutting back herbaceous material, harvesting edibles
Yields: Beneficial insect habitat, beautiful flowers, herbs, medicinals, edibles

Element: Honey Bees
Use: Provide honey, added pollination
Size: 1 beehive
Relationship: Learning experience on how to keep bees
Character: Nestled in pollinator garden with dappled shade, southern sun and protection from strong winds
Needs: Daily care and maintenance
Yields: Honey, enjoyment, learning, pollination services

Element: Rainwater collection
Use: Provide alternative source of water, reduce runoff, used for irrigation, water for animals
Size: Gutter on part of barn roof with rain barrel
Relationship: Close to chickens, new vegetable garden, swale, and forest garden/windbreak to provide water to chickens and irrigation during plant establishment
Character: Big blue drum
Needs: Construction/implementation
Yields: Gravity-fed water

Element: New garden site
Use: Vegetable garden with less flooding and saturation risk
Size: 80' x 100', but could start smaller and grow

Relationship: Close to house, located in warm microclimate south of barn, close to chicken manure
Character: reduced-till and no-till, rotational plantings with cover crops, companion planting
Needs: initial tillage, double-digging, applications of organic matter
Yields: Vegetables and herbs

Element: Fertigated pool
Use: Provide nutrient-rich warm water for irrigation
Size: ~ 5x5'
Relationship: Fertigation for rice paddies
Character: Small, not very deep, lined with clay
Needs: Fertilization from manure, urine, or ducks
Yields: Nutrient-rich, warm water

Element: Rice paddies
Use: Provide staple crops in increasingly warm climate
Size: ~ 10x12'
Relationship: Below existing pond and fertigation pool in elevation, in wet field with lots of clay next to vegetable garden
Character: Able to be filled with 8" of water, 12-14" berms on the lower side, lined with clay and built up silt with soil on top
Needs: Earthworks to construct, maintenance, planting, weeding, harvesting, water, drainage
Yields: Rice crops, water

Element: Cranberry bog/pond
Use: Provide aquatic habitat and production of cranberries and aquatic medicinals
Size: ~ 30x20'
Relationship: Below rice paddies to receive drainage water for cranberry harvesting, capture nutrients from rice paddies
Character: Deep in one end with cattails, watercress, perhaps tilapia or some other type of fish, shallow cranberry shelf
Needs: Water, flooding/drainage
Yields: Cranberries, cattail, watercress, fish, potentially other aquatic crops

Element: Stream restoration/conservation/water filtration
Use: Filter nutrient-rich water from rice paddies and cranberry bog, provide wildlife habitat, naturalize stream and remove invasives
Size: Variable, ~ 10' wide
Relationship: Below fertigated rice paddy/cranberry bog/pond/swale system
Character: Dense, woody, perennials, grasses, ferns, lush, teaming with wildlife
Needs: Implementation
Yields: Water filtration, wildlife habitat, erosion control, invasives control

I will go into more detail for some of these design elements in the detailed design section.

Detailed Design

The detailed design proved to be a very important part of my design visualizations and information for the client. Extensive thought and research went into the detailed planting plans that considered native/non-native, productive capacity, habit of growth, preferred soil and climate, harmony with surrounding plants, nitrogen-fixing, dynamic bioaccumulation, root structure, habitat for beneficial species and other wildlife, blooming times, color, pollinator support, among other factors. Most of the plants I suggest planting in the landscape come from Jacke's (vol. 1, 2005) *Forest Gardening's Top 100 Species* (Appendix M), Tallamy's (2007*) 20 Most Valuable Woody and Perennial Native Plants* (Appendix N), *Vermont Rain Garden Manual's* Plant List (Hulett, 2014) (Appendix O), and Jane Sorenson's (2013) *Pollinator Habitat Enhancement Natives* list (Appendix P). Completing detailed design supplements made my designs much more human-scale because it instilled a more thorough understanding of the steps that needed to be taken to realize what I had imagined.

Food Forests

Perennial polycultures are the basis for the ecological agriculture systems on Greenleaf Farm. Forest gardens will take some time to establish and will embody the meaning of adaptive management. I can design forest gardens well to some extent, but it will take observation and experimentation to find the most successful plants and groupings of plants that will flourish in certain areas. Creating a forest garden nucleus around an existing fruit tree will achieve self-maintenance quickly and allow growth to happen outwards (Jacke, 2005). One can grow the forest garden outward by propagating and dividing plants so that they eventually merge. Many forest garden plants can be propagated by layering, which entails burying branches of the plant so that the middle of the branch is buried and can develop roots. This new plant can then be moved elsewhere or left to spread. Other species spread by underground runners, which will expand the forest garden nucleus by allowing natural processes to occur (Jacke, 2005). Practices like this mimic the overall development pattern of many plant communities during succession and can also be a great way to grow nursery stock!

I propose experimenting with understory forest garden plantings around the existing trees in the orchard in my design. I created a section of a small-scale forest garden (microforest garden, tree guild) to show the diverse root structures of various plants, shown below.

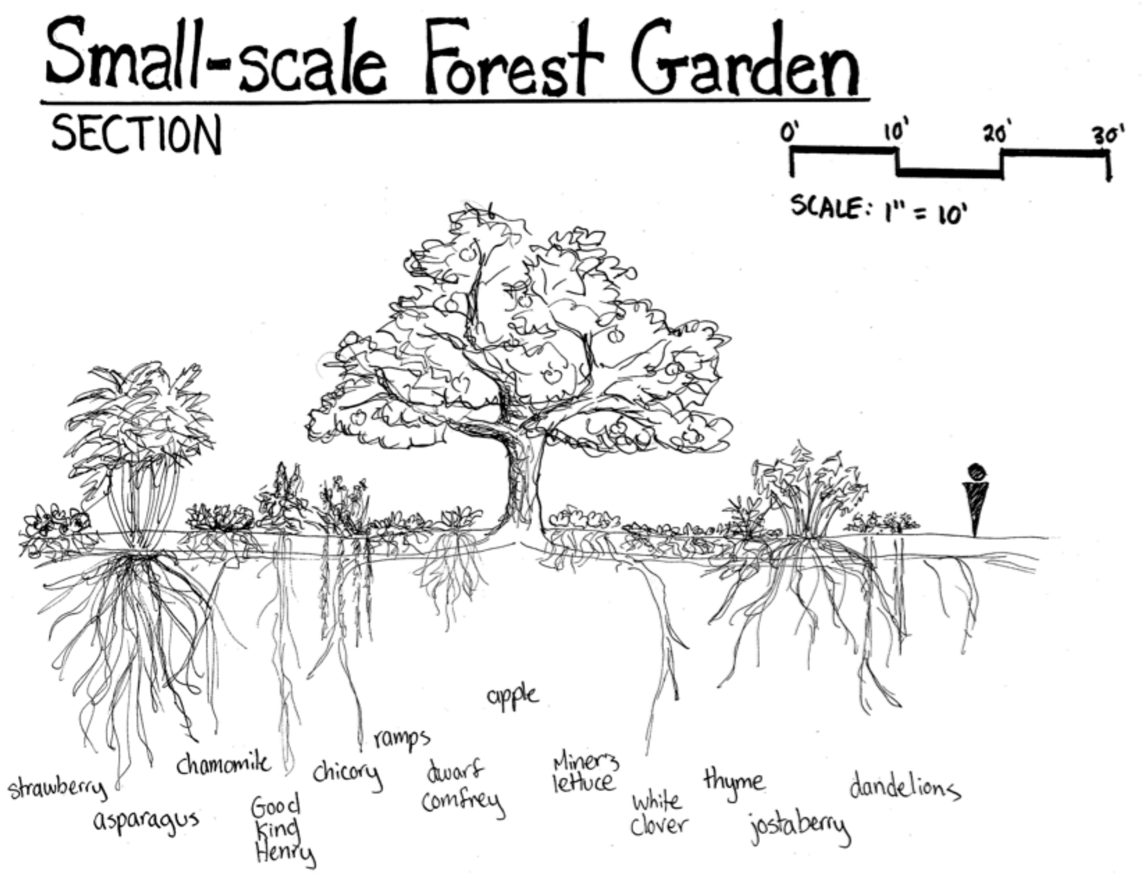

Figure 40. Detail Design: Small-scale Forest Garden Section (Scale 1"=10')

The representations of the root patterns for each species shown came from *Edible Forest Gardens* (Jacke, vol. 1, 2005). This microforest surrounds an existing apple tree in the orchard. Under the apple tree is a fertility and insectary understory as well as an edible greens understory. Comfrey is an excellent forest garden plant that is a dynamic accumulator, groundcover, generalist nectary, invertebrate shelter, and is medicinal (Jacke, 2005). White clover is another great forest garden plant because it is a nitrogen fixer, dynamic accumulator, groundcover, generalist nectary, invertebrate shelter, and can be made into a tea. Miner's lettuce is a groundcover that provides edible greens (Jacke, 2005). Thyme is a medicinal groundcover and generalist nectary that can be used as a culinary herb or to make tea. Ramps (also known as wild leek) are spring ephemerals and provide edible greens and roots and also function as an aromatic pest confuser. Outside of the canopy is an herbaceous perennial border. Chicory provides edible greens that are medicinal and can be made into a tea, and functions as a dynamic accumulator, generalist nectary, and invertebrate shelter. Good King Henry provide medicinal edible greens. Chamomile is a medicinal herb groundcover that can be made into a tea and functions as dynamic accumulator and specialist nectary. Asparagus is a perennial vegetable with medicinal edible shoots. Jostaberry provides edible fruit resembling tart, fruity blueberries. Strawberries function as a groundcover that is a dynamic accumulator and generalist nectary and provide edible fruits that are medicinal and can be made into tea. Finally, dandelions, often thought of as a weed, have numerous forest garden benefits. Dandelions are dynamic accumulators, generalist nectaries, invertebrate shelters, and provide edible greens and flowers that are medicinal and can be made into tea (Jacke, 2005)! Jacke (2005) makes an educated guess that mixing plants with different root pattern types, aboveground phenology, and nutritional profiles will lead to fuller use of the soil profile and thus, reduced competition and increased production (like the design below).

I designed a windbreak that also functions as a food forest to protect the new garden site and planted swales from northwestern winds. A section of the windbreak can be seen on the next page, figure 41. On the northern side is a Korean nut pine, which is very adaptable and provides delicious pine nuts, but may take many, many years to start producing. South of the nut pine is a shagbark hickory, which is a hardy native upland species that is long-lived, low-maintenance, and provides excellent flavoured nuts. Grafted varieties will have nuts that are easier to open. Two species must be planted for pollination. Both Korean nut pines and shagbark hickories have taproots and shallow roots. On the south is a mulberry tree that is a reliable, low-maintenance fruit producer. Mulberries have wide spreading root systems. The understory consists of French sorrel, groundnut, mulitplier onion, lovage, and comfrey. French sorrel provides gourmet edible leaves with a lemony flavor and is one of the best dynamic accumulators, mining calcium, phosphorus, and potassium from the subsoil (Jacke, 2005). Groundnut is a native, nitrogen-fixing, herbaceous vine that produces edible tubers, high in protein. The multiplier onion is one of the most productive root crops, producing edible bulbs; it is also an aromatic pest confuser. Lovage provides edible leaves and shoots with a lemon-celery flavor early in the season. It is low-maintenance and a specialist nectary source. Finally, I have included comfrey because it is a dynamic accumulator and provides excellent nutrient-rich mulch.

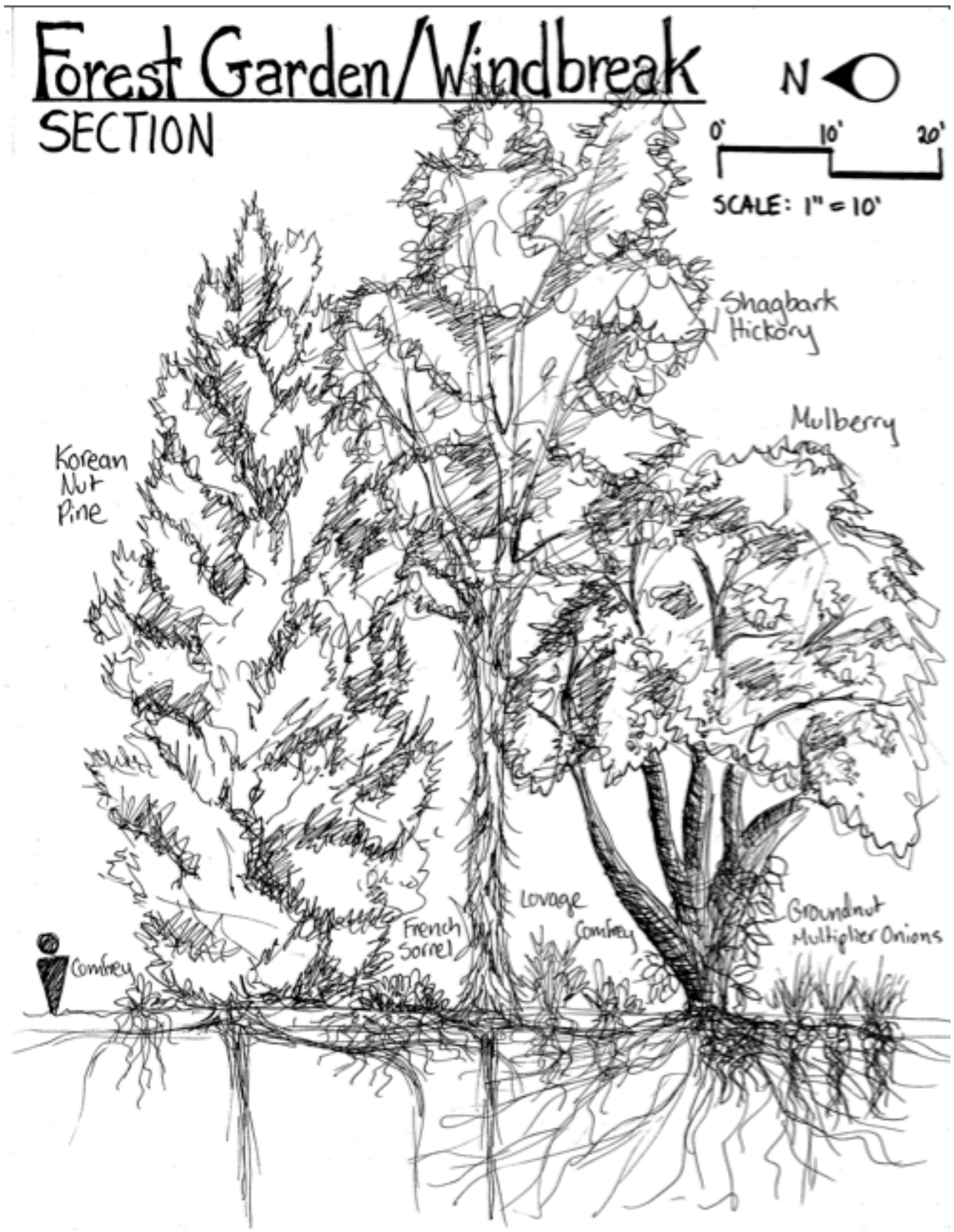

Figure 41. Detail Design: Forest Garden/Windbreak Section (Scale 1"=10')

Swales

Swales passively irrigate the area below them by stopping or slowing the flow of water and dispersing the water well below the swale—five, ten, and even twenty feet downhill (Falk, 2014). For this reason, swales are an amazing soil and plant regeneration tool. Falk (2014) found that all species of plants respond positively to being on a mound, and the increase in growth and health varies from moderate to extreme. Falk (2014) has seen plants respond with twice the growth rate, including species such as black locust, goumi, elderberry, currant, gooseberry, cherry, peach, and apple. This is due to the fact that getting above the water table and periodic inundation during rain and snow is beneficial (Falk, 2014). This function will become increasingly important with climate change and increased events of water inundation. Increased productivity is also due to that fact that swales add surface area and soil-air interface, where biological activity and soil health is concentrated (Falk, 2014).

I designed a swale with a planted mound to take advantage of passive irrigation by replenishing groundwater. I made a perspective drawing of a swale and mound to better illustrate these systems, inspired by Ben Falk (2014), shown on the next page, figure 42. The swale is a shallow ditch, 18 to 24 inches deep, which is seeded heavily with clover (nitrogen fixer) and other species. The topsoil dug from the swale is pulled to the downside slope to hold water. The mound is planted with shrubs, such as Juneberry, and/or trees, as well as an understory. Comfrey is a great understory, functioning as a dynamic accumulator and green mulch (nutrient-rich). A thick mulch ring (3-6”) is then placed around the plants with an underlayer of burlap or cardboard for increased weed suppression. Finally, a cover crop is seeded immediately after earthworks and planting to prevent erosion, comprised of quick-growing annuals and multifunctional perennials (Falk, 2014).

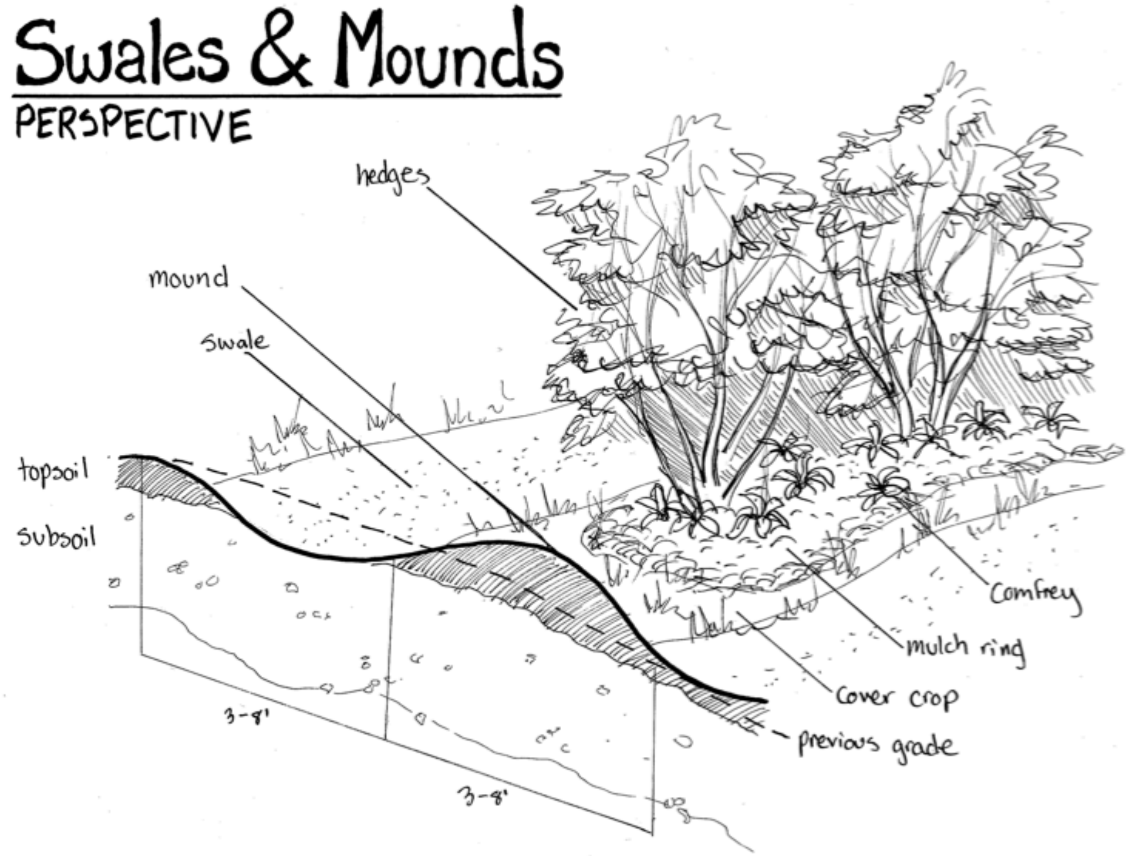

Figure 42. Detail Design: Swale & Mound Perspective

Figure 43. Example of a planted swale from a tour of Ben Falk's Whole Systems Research Farm (2013)

Fertigated-rice paddy-cranberry bog-pond-swale-water filtration System

Rice growing depends on a water- and gravity-based nutrient distribution system that has allowed humans to grow rice successfully in the same location for thousands of years without destroying the land's ability to produce the crop (Falk, 2013). Rice production meets the challenge to grow a climate-durable, reliable staple crop without degrading the fertility of the land by employing several principles: slowing and infiltrating water, growing on contour, growing the most reliable and vigorous genetics possible, growing intensively using biological labor instead of technical inputs, capturing as much nutrients as possible, and returning all nutrients back to the system (Falk, 2014). Rice is very nutritious for a grain, adaptable in recipes, and stores very well, making it a very resilient food source. Falk (2014) found that rice-producing paddies offers the most immediate yields and application possibilities on Vermont's hillsides. It is important to have high yields from intensive annual cropping systems integrated with perennial polycultures. For example, a rice paddy system in addition to a nuttery (planted of chestnut, oak, walnut, hazelnut, etc.) provides short-term and long-term sources of staple foods (Falk, 2014). Perennial polycultures take much longer to start yielding and provide an excellent backdrop and balance to annual cropping systems. Rice grown in paddies can handle extremes of both drought and flood with ease because it grows in an already flooded environment with a consistent source of water.

I designed a fertigated and filtered production system largely inspired by Falk's (2014) fertigated rice paddy system, shown on the following page, figure 44. It consists of two rice paddies to begin with, stacked above one another, with water fed to the rice via gravity from the existing pond. The pond harvests sun, which serves to warm the water, aiding in rice growth, and serves as a storage system between rain events. The water leaving the pond flows through one-inch poly tubing to a small pool just above the rice paddies, which functions as the fertigation input pool. Chicken manure and human urine can be introduced in the pool to create a manure tea pool. This provides a source of warmed, nutrient-rich irrigation water for the paddies. In the future, ducks can be introduced to this system by allowing them to fertilize the pool. Water from the pool is fed through three-quarter-inch poly tubing as needed to the rice paddies below.

Figure 44. Detail Design: Fertigated & Filtered System, Section-elevation (Scale 1"=40')

Introducing ducks into this system can greatly reduce weed pressure, because ducks eat most aquatic plants but not rice with its high silica content (Falk, 2014). This system of combining irrigation with fertilization (fertigation), combined with growing in a detention basin (paddy), makes it sustainable and resilient because it captures most, if not all, the nutrients flowing across the land (Falk, 2014). When the rice is ready to harvest, the paddies are drained into the pond below them.

Figure 45. Rice Paddies at Ben Falk's Whole Systems Research Farm during a tour (2013)

The pond below the rice paddies is deep in the lower half and has a shallow shelf in the upper half. Cranberries will grow on the shelf and will not be submerged in water for most of the growing season. The cranberries grow in a "bog", consisting of a base layer of clay, then gravel, peat, and sand on top (Cape Cod Cranberry Grower's Association, 2014). Cranberries are harvested in the fall by flooding the bog so that the berries float to the surface. The harvest of the rice paddies can be integrated with the harvest of the cranberries to create a multifunctional drainage and flooding system. In the deep end of the pond, wetland medicinal species can be grown, such as watercress and cattails (Falk, 2014). Below the pond is a series of swales and mounds to capture and utilize any nutrients that have escaped the system. Various vegetables and fruits can be grown here including squash, melons, currants, or gooseberries.

The rice paddies, cranberry bog, pond, and swales are located in the wet field to the west of the vegetable garden that slopes into the field to the south. The water from this system flows into a seasonal stream. Currently, the stream is grown in with peppermint, reed canary grass, and nut sedge, all of which are opportunistic and vigorous growers. In my design, I have removed these invasive species and have planted native wetland plants that can withstand drought and water inundation. The purpose is to filter any leftover nutrients in the water from the production system above, before the water runs off the land. It will also restore the stream from being invaded by only a few species and provide diverse habitat for wildlife. The plants selected will come from *The Vermont Rain Garden Plant List* (Hulett et. al., 2014) because they tolerate dryness as well as water inundation. Some good selections from this list are summersweet, spicebush, ninebark, beebalm, foxglove, goldenrod, joe pye, black-eyed Susans, milkweed, and aster, which are all good pollinator supporters as well.

Pollinator Garden

Pollinators are crucial components of any agricultural system, especially native bees. Seventy percent of agricultural crops benefit from pollinators (Ricketts, 2013). Most fruit and vegetable crops rely on pollination or benefit significantly from pollination. Ensuring the presence of native bees is essential for a healthy and integrated agricultural system. In a study by Nancy Adamson (2012), it was found that three quarters of flower visits through the growing season were by native bees on the Virginia farms studied. There are over 4,000 North American species of native bees with variable foraging times and tongue lengths so that a much wider range of plant species gets pollinated (Xerces, 2011). In the northeastern U.S., more than eighty species of native bees have been observed pollinating various berry crops (Mader, 2011). Not only do pollinators provide food and resources for humans, they also help keep natural plant communities healthy and productive. In riparian areas, pollinators support plant communities that in turn stabilize soil and prevent erosion, keeping rivers clean (Xerces, 2011).

I designed a native pollinator and edible garden to surround the beehives on the southern and eastern side of the garden shed to support pollinator foraging and nesting. The pollinator garden to the east of the garden shed also functions as an ornamental garden with various medicinal and aromatic species. The color scheme of this garden is mainly blue, purple, yellow, and white to attract primarily native bees and to be aesthetically pleasing (Xerces, 2011). Wild senna and blue wild indigo are nitrogen fixers, aiding in building soil fertility. Purple coneflower, great St. John's wart, and yarrow are all medicinal. Spotted beebalm, summersweet, and anise hyssop are fragrant species providing stimulation to multiple senses.

Figure 46. Detail Design: Native Pollinator & Edible Garden (Scale 1"=10')

Figure 47. Sample of flowers in pollinator garden to attract native bees, from left to right by row: summersweet, spicebush, anise hyssop, baptisia, wild senna, great St. John's wart, meadow evening primrose, spotted beebalm, purple coneflower, hairy beardtongue, wild geranium, kinnikinnick

The garden to the south of the garden shed is primarily edibles that also support pollinator foraging, including: wild strawberry, low bush blueberry, wild black currant, Indian current, northern gooseberry, eastern prickly gooseberry, and swamp red currant. I also proposed to plant a Pawpaw tree, which is the largest native fruit to the northeast and very delicious. It has a hardiness zone of 5b, which is a bit warmer than the site, but may have a shot in this warm and sunny microclimate and is worth experimenting with. This garden is designed around an existing black locust tree and an old sandbox. The black locust is a great pollinator supporter, with early season (May-June) fragrant blooms. It is also a nitrogen fixer. I intentionally left the sandbox because it provides an excellent nesting habitat for ground bees. Seventy percent of native bees nest in the ground, while 30 percent nest in tunnels bored into wood (Xerces, 2011). Therefore, it is important to leave open sandy ground and old woodpiles or dead snags alone. There is an area in the middle of the garden for the honeybee hives and a bench to observe them. At the entrance to this trail is a trellis with native fox grape. The grassy areas around the bench and edibles will be comprised of fine fescues, white clover, dandelions, Labrador violets, Canada violets, thyme, and spring beauty. These species will make a beautiful lawn that does not need to be mowed (fescues grow to about 6 inches) and includes nitrogen fixers and dynamic accumulators (white clover, dandelion). In addition, the violets and thyme are edible and spring beauty produces edible roots.

As part of my detailed design, I have proposed to include native bee boxes in the garden. These look somewhat like bird houses but are made of solid wood with various sized holes drilled into them or hollow houses with dried phragmites grass inside of them. The various sized holes provide habitat for diverse native bee species.

Figure 48. Examples of bee houses during a tour at John Hayden's diversified fruit and berry farm, The Farm Between, Jeffersonville, VT (2013)

Raised Beds & Edible/Ornamental Gardens

I drew a perspective drawing of the front of the house, showing the raised beds, edible and ornamental front gardens, and solar panels and hot water system, shown below. The raised beds are 4 by 6 feet and are made of cedar from on-site. They contain dense plantings of vegetables, herbs, and flowers. They include tomatoes, greens beans, squash, watermelon, melon, basil, red basil, lavender, chamomile, marigold, mint, chives, lavender bee balm, rosemary, sage, thyme, and oregano. For the edible and ornamental gardens, I included hardy kiwifruit to climb up the columns on the porch. In front of the porch I have included blueberries, foamflower, Labrador violets, alpine strawberry, and wild strawberry. Labrador violets are edible while foamflowers are good specialist nectaries. In the front of the main house, I have included red osier dogwood, flowering dogwood, kousa dogwood, chinquapin, and bush cherries. Chinquapin is a native shrubby cousin to the American chestnut. I placed bush cherries along the driveway because they are extremely hardy and provide excellent hedging, producing profuse white blooms in the spring and fruits that can be eaten raw or in preserves. An elderberry tree and hops vine already exists. I also suggest planting a hazelnut in the chicken yard so that the chickens can protect it from squirrels. Planting a Siberian pea shrub next to it would fix nitrogen and provide edible beans for the chickens.

Figure 49. Detail Design: Raised Bed & Edible/Ornemental Front Gardens, Perspective

Presentation

The presentation consisted of 5 large foam boards (30”x40”) displaying my design drawings. The site analysis drawings were in the first board. Site assessments were on the second board. On the third board were conceptual diagrams and on the fourth was the schematic plan. Design details occupied the fifth board. The presentation also included a slide show consisting of goals, site context, various map layers that I did not physically present, photos of plants, and examples of proposed design elements. The purpose of the presentation was as if I were presenting to a potential client.

Conclusion

The landscape master plan I have designed provides a good first step to improving resiliency on Greenleaf Farm. It provides a framework to develop ecological resilience as well as agricultural resilience. Applying the concepts of complexity and diversity were key to the design—on the site scale and design detail scale. I found that developing resiliency revolves around plants and the conditions to improve the productivity of plants. Proper management of soil and water is key—but mainly for the purpose of growing plants. Plants act as a protection against variable weather conditions, while also building topsoil and fertility with organic matter and capturing valuable nutrients in the ecosystem. The plants most suitable to perform these vital functions on the landscape were most often native plants that have adapted to this region, or other plants adapted to similar regions, particularly perennials. Perennial polycultures were the basis for a resilient ecological agriculture system on Greenleaf Farm. Perennial plants provide a sustainable and resilient food source as well as economic income. In addition, it was necessary to secure essential natural sources for humans, including potable water, solar energy, and food processing and storing infrastructure. Livestock can be beneficial to integrate into agricultural systems as well, increasing fertility and diversifying resources.

The overall goal of my project was to increase resilience on Greenleaf Farm. I found that resilience is a function of a diverse ecological structure. The more diversity and complexity I can create in the structure of the system, the more beneficial relationships will emerge and resilience will develop. In order to develop a truly resilient homestead and farm, the people living there must have a connection to the landscape and/or motivation to establish these long-lasting systems. It is possible to create a resilient landscape while also achieving agricultural and economic resilience, demonstrated by Ben Falk at Whole Systems Research Farm. However, this takes a strong dedication by one or many people to achieve.

The achievement of true resiliency in a changing climate lies in creating and allowing beneficial relationships to emerge between the surrounding ecological system and the people that inhabit it. Resiliency is ultimately a goal of symbiosis between humans and the natural world—evolving to be mutually beneficial. Currently, nature is much more beneficial to humans than humans are to nature, overall. Unless people develop the systems to benefit ecological processes and patterns, then nature will become decreasingly beneficial due to climate change and loss of soil and fertility. It is up to us to reimagine this relationship that has been far too one-sided for far too long. Resilient ecological systems are about creating balance; it is time to develop a balance between all the other species in the world and our own species.

The dedication of individuals on small sites around Vermont to develop stability and connectivity with agricultural and land management methods will create a better whole that is more resilient to the impending climate changes we face and will benefit everyone.

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Appendices

Appendix A. Potential Impacts of Climate Change Analysis Map Layer

Appendix B. Site Analysis: Slope, Hydrology (Scale 1"=400')

Appendix C. Table of Soil Descriptions (information retrieved from USDA NRCS, 2014)

Appendix D. Site Analysis: Topography (Scale 1"=150')

Appendix E. Site Analysis: Soils (Scale 1"=150')

Appendix F. Site Analysis: Vegetation (Scale 1"=150')

Appendix G. Site Analysis Process-Rough Draft (Scale 1"=40')

Appendix H. Site Analysis: Topography, Hydrology, Slope (Scale 1"=40')

Appendix I. Site Analysis: Soils, Drainage (Scale 1"=40')

Appendix J. Site Analysis: Draft (Scale 1"=40')

Appendix K. Initial Concepts (Scale 1"=40')

Appendix L. Draft Conceptual Diagram (Scale 1"=40')

Appendix M. Plant List: Forest Gardening's Top Species

Appendix N. Plant list: Valuable Woody and Perennial Native Plants

Appendix O. Plant List: The Vermont Rain Garden

Appendix P. Plant List: Pollinator Habitat Enhancement—Native Plants

Appendix Q. Alexander Pope, *An Essay On Man* (1734), Excerpt

"Consult the genius of the place in all;
That tells the waters or to rise, or fall;
Or helps th' ambitious hill the heav'ns to scale,
Or scoops in circling theatres the vale;
Calls in the country, catches opening glades,
Joins willing woods, and varies shades from shades,
Now breaks, or now directs, th' intending lines;
Paints as you plant, and, as you work, designs.

Still follow sense, of ev'ry art the soul,
Parts answ'ring parts shall slide into a whole,
Spontaneous beauties all around advance,
Start ev'n from difficulty, strike from chance;
Nature shall join you; time shall make it grow
    A work to wonder at—perhaps a Stowe."