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# Using Phytotechnology to Redesign Abandoned Gas Stations

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# Abstract

Hazardous pollutants that exist in contaminated soils represent a threat to human, animal, and environmental health if left unmanaged. Phytoremediation in the U.S. was generally named and formally established in the 1980s and applied as an alternative method using plants to cleanse contaminated soils on site in a more economically and environmentally friendly way than removing contaminated soils off site. High expectations and mixed performances with failures outnumbering successes led to a crash of phytoremediation with a decline in environmental research funding by the early 2000s. "Phyto", a book by landscape architects Kennen and Kirkwood (2015) recently reintroduces the subject with a more approachable set of planning, engineering and design tools. One commonly occurring site with a history of perpetuating contaminated land is the abandoned gas station. Abandoned gas stations are highly visible in the landscape and if soils are contaminated then remediation costs can hinder redevelopment. The focus of this project is the redesign of abandoned gas stations through phytotechnologies by applying and expanding Kennen and Kirkwood's (2015) framework.

Phytotechnology as a means for remediating small sites polluted with organic chemicals is a step in promoting this technology and proving its worth for other, larger and more complicated brownfield. While this study explores one possibility of redesigning an abandoned gas station on a highway corridor in Hadley, Massachusetts (USA) it is necessary to expand design possibilities on other abandoned gas stations with different contexts and conditions. The results should also be extended to gas stations in operation to apply phytotechnologies as a preventive method. This design study is relevant for the profession of landscape architecture because it merges design aesthetics with science-related technologies. There are still aspects that have been overlooked or need more exploration: process-oriented strategies especially public participation. Implementing and promoting this type of remediation will require community support and involvement, of which can be directed and associated with an experiential transformation of such abandoned and contaminated sites. These findings may be accompanied within a regional process of identifying and networking potential sites while considering them within an established city greenspace or greenway plan.

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# Introduction and Background

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Changes to the landscape in Post-Industrial America are evident through the continual increase of brownfield sites in the country as a result of a declining industrial economy (Nassauer and Raskin 2014). Brownfields are defined as real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant (US EPA 2008). Hazardous pollutants that exist in these contaminated soils represent a threat to human, animal, and environmental health if left unmanaged.

One commonly occurring site with a history of perpetuating contaminated land is the gas station. These establishments proliferated throughout the United States in the 20th century as major oil companies overbuilt their chains attempting to succeed in the battle for territorial gain (Jakle 1994). This competition created an overt presence in the American landscape and in recent decades the abandoned gas station has become just as significant a symbol in our culture as they have brought a certain dereliction to almost every American neighborhood (Jakle 1994). This has created a growing need for innovative, sustainable, low-cost methods to address the contamination issues prevalent in soils and groundwater (Kennen and Kirkwood 2015).

Typically, the remediation process consists of any number of methods to fulfill the goal of cleansing the land of harmful pollutants. Popular methods include the removal of soil to be dumped in a landfill or encasing the polluted soils within a membrane to prevent any leakages (Hollander 2010). These methods, while effective at some levels, are expensive processes that merely dismiss environmental concerns by displacing the burden or hiding it for a later discovery. Industrial solvents, fuel components, paints, adhesives, gasoline, and plastic are commonly found contaminants in brownfields (Kang 2014). The majority of pollutants seen at typical gas stations are organic chemicals that can be removed from the soil and groundwater using plant life.

Many researchers have stepped up the efforts to find more sustainable and cost-effective alternatives to these processes including the field of phytoremediation (Kang 2014). Phytoremediation utilizes plant life to eliminate toxic organic contaminants from groundwater and soils. This process presents major advantages compared to other remediation technologies, as it can be applied to a broad range of organic pollutants and some heavy metals while maintaining minimal environmental disturbance at a much lower cost (Schroder et al 2002) totaling as little as 3% of the cost of traditional cleanup costs (Kennen and Kirkwood 2015). In short, phytoremediation is the process where vegetation is planted where pollutants in the soil are known or expected to allow for the natural processes of the plant to treat the contaminated soil and restore it to healthy levels (Peuke and Rennenberg 2005).

Phytotechnology, a broader definition for phytoremediation (Kennen and Kirkwood 2015), utilizes vegetation to remediate, contain or prevent contaminants in soils, sediments and groundwater, and/or add nutrients, porosity and organic matter. It also creates a more approachable set of planning, engineering and design tools combined with cultural practices, such as education, that can assist multiple professions in engaging with the cleanup of contaminated sites, particularly landscape architects. This approach to remediating a contaminated site can be beneficial because it offers an in-situ opportunity that reduces the amount of contaminated wastes that need to be disposed while also providing a more economical option when compared to traditional remediation techniques (McCutcheon 2003).

During prospective initial stages, when the sites soil is still deemed inhospitable, the process involved with phytotechnology applications can exhibit an interactive and educational component for the community. Understanding how and why a location is now unusable and what will happen to it going further enhances public understanding of current day-to-day actions. This begins the goal of elucidating what brownfields are and what an be done with them.

Upon full remediation, a gas station can offer recreational or ecological function that benefits society or provide a pragmatic use such as returning to function as a gas station or retail space. This has been shown to increase property values (Kaufman and Cloutier 2006; Linn 2013; Mihaescu 2012) while also achieving success in the community (De Sousa 2006). Contributions would include scenic beauty, appeal, improved access to trails, recreation space, and connection with nature which would boost pride and remove blight (De Sousa 2006). Under circumstances dependent on the growth of the urban area the site is fully capable of being developed for nearly any purpose which offers a more sustainable land development choice by preventing a virgin greenfield from being developed which attenuates the negative consequences associated with urban sprawl, greenhouse gases, and climate change (Hollander 2010).

## Project Goals

The goal of this project is to develop design ideas and strategies that reflect long-term remediation processes while using phytotechnology as a tool for aesthetic experience, performance and resilience to redesign abandoned gas stations. The framework of knowledge necessary for understanding how plant mechanisms interact with pollutants is gathered from the 2015 book “Phyto” by Kate Kennen and Niall Kirkwood (Figure 1.1).

This project explores the potential for phytotechnology as a meaningful opportunity for brownfield remediation and demonstrates how phytotypologies, a series of phytotechnology planting schemes, can be used in combinations for varying situations at abandoned gas stations. These applications have been selected due to their ability to remediate

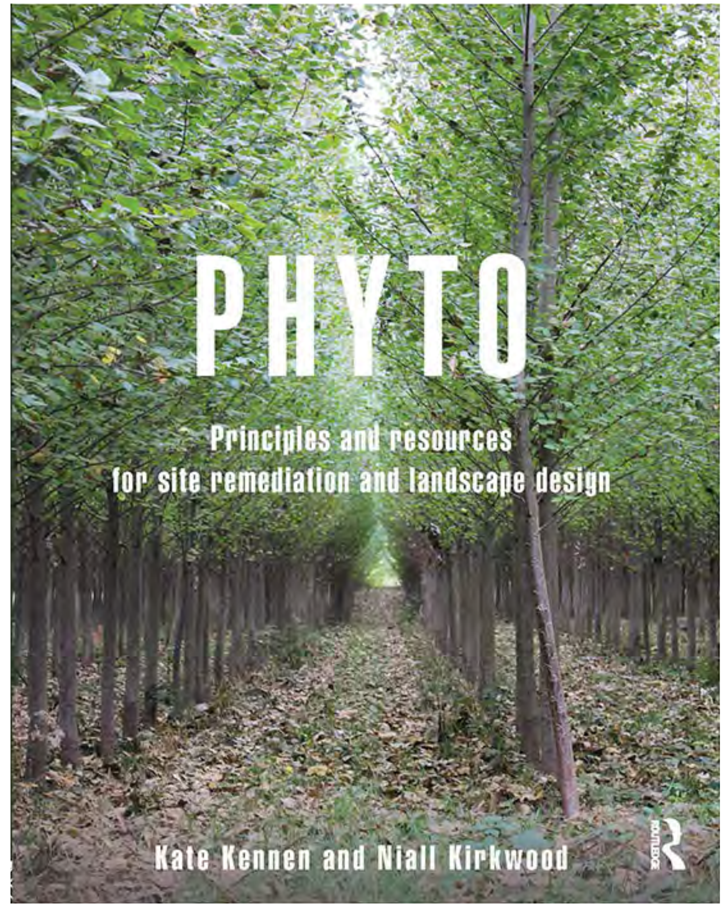



Figure 1.1 shows the book that was heavily relied upon for understanding and applying phytotechnology principles.

the types of contaminants present at typical gas stations. It is seemingly well known and displayed how a grouping of trees and plants can be placed in a position to remove pollutants, but this process has been relegated to an event and not a comprehensive experience that will include connectivity and educational purposes.

This project uses an abandoned gas station located on Massachusetts Route 9 outside of Amherst, MA as a study area, wherein a theoretical contamination problem is presented. This project explores, through design, the possibility of creating and planning for an experience of the healing process at gas stations as ubiquitous brownfields that are applicable for other geographical contexts all over the world. Furthermore, implementing and promoting this type of remediation will require community support and involvement, of which can be directed and associated with an experiential transformation of such abandoned and contaminated sites. These findings may be accompanied within a regional process of identifying and networking potential sites while considering them within an established city greenspace or greenway plan.

This design proposal will elucidate the ability of abandoned gas stations to transform into a cleansing landscape while merging other ecological and cultural functions through soil and groundwater remediation using phytotechnology. This includes how these sites can utilize phytotechnology in an aesthetically pleasing experience, changing public perception while maintaining efficient functionality in the remediation process to inevitably provide a site that benefits the community.

# Literature Review

# Literature Review

The literature review encompasses three different parts. The first part covers general challenges and opportunities of urban brownfields, conventional remediation techniques and alternative-treatment technologies. The second part delves deeper into phytoremediation as one alternative technique including phytoremediation processes and a general overview about plants that are recommended for phytoremediation. The third part covers comprehensive methods and models of phytoremediation, synthesizes them as they may apply to landscape architecture, and are defined as phytotechnologies. This part furthermore introduces rare research-by-design work on larger spatial concepts that are based on phytotechnologies. This third part introduces the challenges and opportunities of phytotechnologies for abandoned gas stations as landscapes. This includes the plant typologies.

## Urban Brownfields

There is considerable literature supporting the benefits of turning urban brownfields into greenspaces (Siikamaki and Wernstedy 2008; Bonthoux et al 2014; De Sousa 2006; Harnik and Donahue 2011, Kattwinkel et al 2011; Kaufman and Cloutier 2006; Mathey and Rossler 2015; Siikamaki and Wernstedt 2008). This research purports a variety of different reasons for these benefits ranging from visual preference (Mathey and Rossler 2015), urban biodiversity (Bonthoux et al 2014), increasing property values (Kaufman and Cloutier 2006) and positive community surveys (De Sousa 2006). There is unquestionable doubt that brownfields possess the intrinsic potential for becoming environmental or community green space that can clearly stimulate the city's built environment while at the same time remediate contaminants and transform socially and environmentally neglected urban areas (De Sousa 2004). With that said a significant minority, comprising 3-4%, of brownfield redevelopment projects are intended for these uses (De Sousa 2006). One of the major reasons for this is the enormous cost associated with many brownfield remediation projects (Siikamaki and Wernstedt 2008).

Revitalization powered by the promise of housing opportunities and economic gains through jobs, tax revenues and increased revenues as a result of residential and commercial redevelopment often overshadow the invisible, qualitative and long-term benefits associated with green space development (Siikamaki and Wernstedt 2008). These invisible benefits are not lost on the average individual as surveys conducted have shown that 90% of respondents believe that greenspace is a good use of brownfields in their community (De Sousa 2006). Information like this suggests a broader range of uses for urban brownfields helps raise the quality of life among residents which promotes future investors and economic stability back to what was considered voids in the community (De Sousa 2006). To influence further prosperity in returning urban brownfields to green spaces the difficulties associated with that transition must be addressed, specifically cost and expectation.

## Conventional Remediation Techniques

Determining how a brownfield will be reclaimed requires many levels of insight that elucidate the site-specific constraints hindering development. Most importantly, considerations must be made regarding the type of contamination, level of contamination and acceptable cleanup standards, as these factors influence the typical methods that will be employed for site remediation (Hollander 2010). Hollander 2010 breaks down an array of methods available for cleanup into three categories: established treatment technologies, innovative alternative-treatment technologies, and emerging alternative-treatment technologies.

Established treatment technologies include: air sparging, a technique that injects air directly into severely polluted groundwater to remediate it by volatilizing contaminants; bioventing, which injects air into soil to stimulate natural biodegradation of pollutants; encapsulation, or "capping" refers to the installation of a layer of soil, clay, or waterproof membrane that covers and contains contaminated material on site;

excavation, a most common technique that removes contaminated soil and dumps it in a landfill; incineration, the process of removing soil and loading it into a portable incinerator that burns hazardous materials away; and finally a method known as soil vapor extraction where contamination is removed from soil by passing it out through a medium such as air or steam which creates a vapor that can be vacuumed out (Hollander 2010). It is self-evident that these methods express means that treat the Earth as an object for engineering instead of a living organism and although they are the most common possibilities for site remediation, they are very expensive and intensive processes. Many of these applications can cause secondary contamination and damage to the environment (Kang 2014).

The next level of remediation process that Hollander describes are innovative alternative-treatment technologies, which have limited full-scale application due to a lack of data on performance and cost. These include methods that begin to use natural processes to alter the state of the site. These include: bioremediation, which is the use of biological agents, such as microbes, to remove or neutralize contaminants in polluted soils; natural attenuation, a method that relies on natural processes that occur impromptu on a site, but must be guided to ensure success; soil washing, which “scrubs” soil to remove and separate the portion of the soil that is not polluted; and lastly thermal desorption, a process that utilizes heat to increase the volatility of soil contaminants that can be removed (Hollander 2010).

The last category discussed by Hollander is emerging alternative-treatment technologies, which are mostly found on laboratory test plots and full-scale pilot-site testing areas (Hollander 2010). Of particular interest in regards to this project is phytoremediation, or the direct use of living plants to remove or neutralize site contaminants such as heavy metals and organic pollutants found in soils and ground water (Hollander 2010). This process, while much slower than traditional remediation techniques, offers a much less dramatic and less expensive means of site remediation, while treating the land with some semblance of respect. In 2005 phytoremediation comprised $100-150 million per year of the total remediation market, or 0.5% (Pilon-Smits 2005). Factors for this are dwindling research funding sources in the US since 2001 and consequently diminishing support from federal, state and local regulators (Kennen and Kirkwood 2015). This is partly because phytoremediation can be as little as 3% of the cost of traditional cleanup (Kennen and Kirkwood 2015), but is mostly due to its infrequent application.

### Abandoned Gas Stations

Abandoned gas stations proliferated throughout the United States in the 20th century as major oil companies overbuilt their chains attempting to succeed in the battle for territorial gain. This competition created an overt presence in the American landscape and in recent decades the abandoned gas station has become just as significant a symbol in our culture as they have brought a certain dereliction to almost every American neighborhood (Jakle and Skulle 1994). The major problem at these locations is instances of fuel leaks entering the environment. This can happen in a number of ways, but it is most predominately associated with leaking underground storage tanks or LUSTS. From 1984-2011 the United States saw 500,000 instances of LUSTs. This has created a growing need for innovative, sustainable, low-cost methods to address the contamination issues prevalent throughout these sites’ soils and groundwater (Kennen and Kirkwood 2015).

### Contaminants of Abandoned Gas Stations

The contaminants found at any given polluted site can be first separated into two fields, organic and inorganic. Although many gas stations do incur inorganic pollution, especially if it was built prior to 1970, this project does not deal directly with inorganic contamination. However, the challenges and solutions involved in these scenarios is worth noting. Simply put, inorganic contaminants are elements found on the periodic table, such as, zinc, copper or lead (Kennen and Kirkwood 2015). Elements cannot be broken down or degraded as they are at their most basic state. Harmful elements, typically metals, are the most difficult to deal with during a remediation project. They can enter the environment through activities associated with mining, industrial production and the burning of fossil fuels. Methods for dealing with inorganic contaminants through the use of phytoremediation are much less available and less successful. One way to address the issue of inorganic pollution is through extraction and removal of plant material. Extraction allows for plants to uptake the inorganic chemicals and hold them until the plant can be harvested and transported elsewhere for disposal. Another method is stabilization of the inorganics which prevents the movement of contamination from entering a vital water source or area by holding these pollutants in place with the assistance of specialized vegetation. To accomplish this, plants known as hyperaccumulators can be used to absorb certain elements at concentrations 10-100 greater than normal plants (Kennen and Kirkwood 2015). Understanding exactly what needs to be targeted and where they are located is necessary in order to select a plant species or species cultivar that can work most effectively as a hyperaccumulator (Kennen and Kirkwood 2015).

Kennen and Kirkwood 2015 define organic pollutants as, "compounds that typically contain bonds of carbon, nitrogen and oxygen, are man-made and foreign to living organisms." Since these pollutants are compounds it is possible that plants can interact with them in a way that breaks them down into smaller, less toxic compounds (Kennen and Kirkwood 2015). In an ideal scenario it is possible for a specific plant to break down a particular organic pollutant to the point where it is degraded and eliminated as a harmful substance from the soil or groundwater.

Most of pollutants seen at typical gas stations are organic chemicals that are derived from petroleum sources and come in many forms. These chemicals enter the environment through fuel spills, leaky underground storage tanks and botched fuel deliveries. These substances contain hundreds of hydrocarbon compounds that create unfavorable outcomes when they come in contact with people, animals or the surrounding landscape. These petroleum hydrocarbons can be further subdivided into two categories, lighter and heavier fractions. The heavier fractions include PAHs (polycyclic aromatic hydrocarbons), coal tar, crude oil and heating oil. Degradation for these fractions are more difficult and must be done in the rhizosphere of the plant, which is directly in contact with the surface of plant roots where root secretion interacts with the soil (Kennen and Kirkwood 2015). This is because heavier fractions of petroleum are more strongly bound with multiple ring structures in their chemical makeup which makes them have a lower water solubility.

Petroleum compounds that are considered lighter fractions, meaning they have characteristics that allow them to be more easily broken down, are gasoline and gasoline additives like MTBE (methyl, tertiary butyl, ether) and BTEX (benzene, toluene, ethyl benzene, xylene), as well as, diesel fuel. These often have chemical makeups with single molecule chains which are more water soluble and therefore more easily degradable. These lighter fractions are where phytotechnology is most promising and opportune.

### Phytoremediation - Advantages and Disadvantages

Phytoremediation strategies employ trees, shrubs, and grasses for treating contaminated air, soil, or water (Licht and Isebrands 2005). This can be done through buffers, vegetation filters, in situ phytoremediation plantings, and percolation controlling vegetative caps (Licht and Isebrands 2005). Of particular interest to this project is the idea of in-situ phytoremediation. In-situ phytoremediation plantings use trees, shrubs and grasses installed for subsurface treatment of inorganic or organic pollutants (Licht and Isebrands 2005). This approach places the vegetation material where the contaminant on a site exists at concentrations that allow growth so that the particular species can develop root growth to begin attenuating pollutants in the soil (Licht and Isebrands 2005). The literature is dense with scientific research concerning the intricacies of what level of success phytoremediation can have depending on the pollution present. The easiest to remove and most plant accepting types of pollutants have been shown to be organic compounds (Kang 2014; Licht and Isebrands 2005; Peuke and Rennenberg 2005; Pilon-Smits 2005; Schroder et al 2002), while there is a great deal of research regarding the removal of heavy metals from soil as well (Roy et al 2005). Common organic pollutants successfully degraded at field scale using phytoremediation include petroleum hydrocarbons such as oil, gasoline, benzene, toluene, butyl, ether, etc. that come from fuel spills and leaky underground storage tanks (Kennen and Kirkwood 2015). Other common organic pollutants include chlorinated solvents, pesticides, herbicides, insecticides, and fungicides from agricultural application (Kennen and Kirkwood 2015).

Much of the benefits of phytoremediation have been expressed. First, it is a relatively inexpensive process to apply and simple to manage (Kang 2014; Doty 2008). Secondly, it is a passive, solar driven process that does not damage the site being remediated allowing for the retention of topsoil (Doty 2008). Third, it provides site level benefits beyond soil remediation in: site aesthetics, wildlife habitats, carbon sequestration and soil stabilization (Kang 2014). Fourth, it is highly accepted by the public (Doty 2008). It is already known that brownfields are capable of promoting biodiversity in urban areas (Bonthoux 2014), but this has mostly encouraged a hands off approach that allows natural processes to take effect. Phytoremediation of brownfields opens the opportunity for planned levels of biodiversity by urging and facilitating plant growth.

The main drawback to phytoremediation is the time the process takes (Doty 2008). This process can depend on the level of pollution, method employed and what types of pollutants exist, with timeframes ranging from several months to a decade (Pilon-Smits 2005; Doty 2008; Sleegers 2010; Kang 2014; Peuke and Rennenberg 2005). This timeframe can be turned into an advantage if the cleaning stages develop a distinct character and sense of place within a planned framework (Sleegers 2015). Other disadvantages include limitations due to seasonal effects and site specific concerns limiting plant palettes (Kang 2014). Phytoremediation is also constrained to root depth levels of contaminants (Doty 2008).

## History of Phytoremediation

The field of phytoremediation has seen a variety of ups and downs since it became a part of the remediation industry. During the early years of experimentation and use it was erroneously believed to be a panacea for all things contamination (Kennan and Kirkwood 2015). There were hopes that plant material could be used to clean metal-contaminated sites and provide a cheap and easy alternative to traditional remediation techniques. All of these thoughts led to this niche industry being overhyped and implemented without really understanding the intricacies of what makes a successful application.

Advocates of phytoremediation oversold the abilities and as attempts for implementation were being made there ended up being more failures than successes (Kennen and Kirkwood 2015). What had been seen as a silver bullet to contamination in the landscape was actually a delicate science that needed to be understood and studied in a laboratory before being rolled out into the real world. Unfortunately, all of the failures associated with phytoremediation had the unjust effect of destroying its credibility (Kennen and Kirkwood 2015). This limited funding, research and stalled progress for years. Since then, the progress has been slow, but this progress is founded on arduous research. Through this research there is new hope for phytoremediation as a welcome need for remediating contaminated landscapes.

## Spatial Concepts of Phytoremediation

Research-by-design work that incorporates multiscale, spatial frameworks into the more science-oriented theory of phytotechnologies is rare. This research provides possible links between science, practice, cultural and aesthetic values. Wilschut et al (2013) used a landscape design approach that considered scientific knowledge on phytoremediation and formed it into a spatial composition for brownfields of the port of Rotterdam (NL). Understanding a site's potential and the predicted time period for the remediation process allowed for a systematic and transitionary framework with opportunities for combining community oriented programmatic elements that interacted and evolved along with the site (Wilschut et al 2013). This idea of transformative remediation as a systematic design tool provides conceptual bridges between aesthetics and ecological design that can follow principles of green infrastructure and aesthetic experience as a design and planning concept (Sleegers 2014).

Conceptually, green infrastructure would allow for a flexible use of remediated landscapes as ancillary components of larger green infrastructure entities that support a framework for environmental, social and economic health as well (Benedict et al 2006). The ability to integrate a remediated landscape into a more broadly defined role is one of the intriguing parts of brownfield reuse.

## Phytotechnology as an Inclusive Approach in Phytoremediation

Phytoremediation cannot be looked at in insulation and should be considered as interrelated mechanisms. In the more recent research we find efforts to look at phytoremediation in a more inclusive way. "Phytotechnology is about using specifically selected plants, installation techniques, and creative design approaches to rethink the landscapes of the post-industrial age" (Rock 2015). This broader definition for phytoremediation targets the discipline of landscape architecture as it includes natural systems, considers multiple scales between site and region, emphasizes prophylactic approaches, includes green infrastructure and addresses the need to incorporate cultural values (Kennen and Kirkwood 2015). As with phytoremediation, it utilizes vegetation to remediate, contain or prevent contaminants in soils, sediments and groundwater, and/or add nutrients, porosity and organic matter. This approach can be beneficial because it offers an in-situ opportunity that reduces the amount of contaminated wastes that need to be disposed while also providing a more economical option when compared to traditional remediation techniques (McCutcheon 2003).

Phytotechnology can be simplified into a variety of plant processes that transform contaminants. Kennen and Kirkwood (2015) provide a list of phytotechnology processes or mechanisms that explain a particular way in which a plant can work against contaminants. While the different mechanism that evolve the modification of contaminants by plants is explained, it is important to acknowledge that processes may happen simultaneously through plant and supporting microbial activity.

Only organic substances can be transformed through phytotechnologies – mainly phytodegradation and rhizodegradation; in theory inorganic contaminants such as metals can either extracted into the plant or stabilized. Dickinson et al. (2009) state that phytotechnologies are currently – with some exceptions- not practical for field applications in treating inorganics.

## Phytoremediation Processes or Mechanisms

The removal of pollutants from the soil by vegetation is done through a number of different processes or mechanisms. While we find a variety of classifications (Schroder et al 2002; McCutcheon and Schnoor 2003) we will adapt the nomenclature applied by Kennen and Kirkwood in their book for landscape architects (2015, 34-41) for better matching the planting typologies with the specific cleaning processes. It is important to acknowledge that processes may happen simultaneously through plant and supporting microbial activity.

**Phytodegradation** (Figure 2.1) is the most suitable process for organic pollutants since plants can break down the contaminants into safer compounds (Westphal and Isebrands 2001) metabolically through internal processes during photosynthesis (Kang 2014). Internal enzymes and microorganisms within a plants' roots, stems and leaves break down contaminants as they enter the plant. Metabolites can then be used by the plant during its growth process. Like all of these processes, difficulty can be found due to influences of natural conditions and season effects at site specific locations.

**Rhizodegradation** (Figure 2.2) is breaking down organics by root exudates released by the plant and/or the soil microbiology around the roots. The plant still plays a critical role because it creates a supportive environment for the microbes to thrive. (Reynolds et al, 1999)

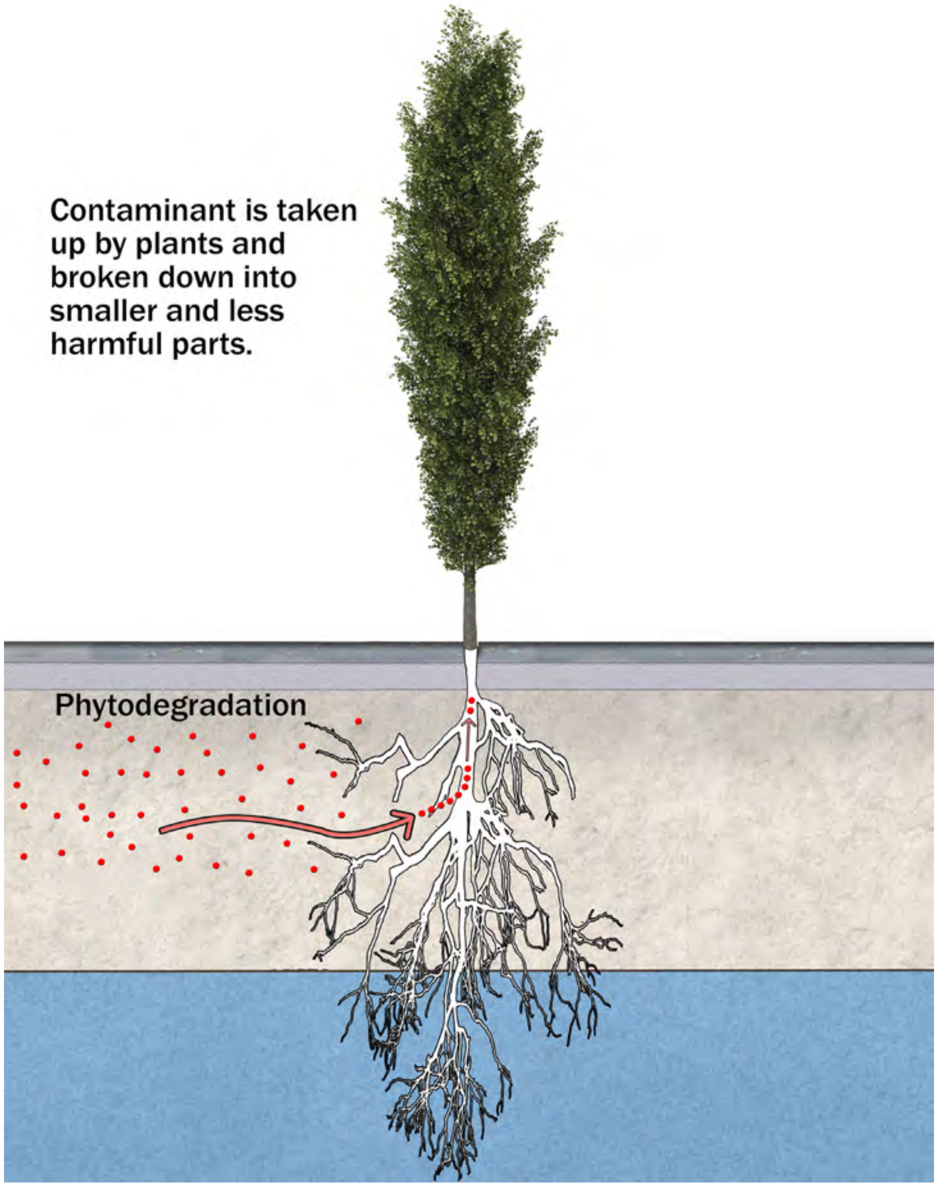



Figure 2.1 Phytodegradation

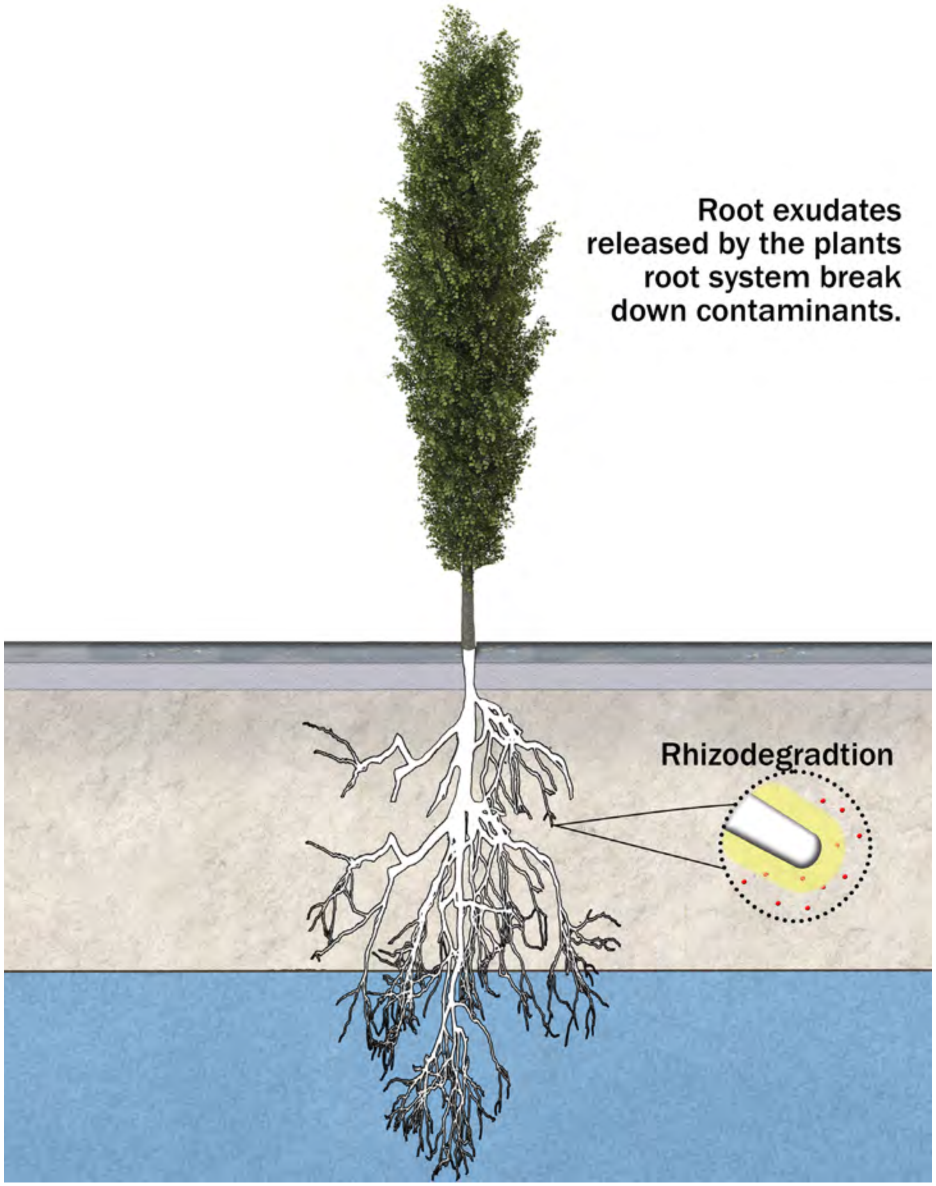



Figure 2.2 Rhizodegradation

**Phytohydraulics** (Figure 2.3) describes the process where plants pull up water, changing the hydrological flow of an areas sub-surface and takes potential contaminants with them. This mechanism is a key part of phytotechnology because of the power a massing of trees can have

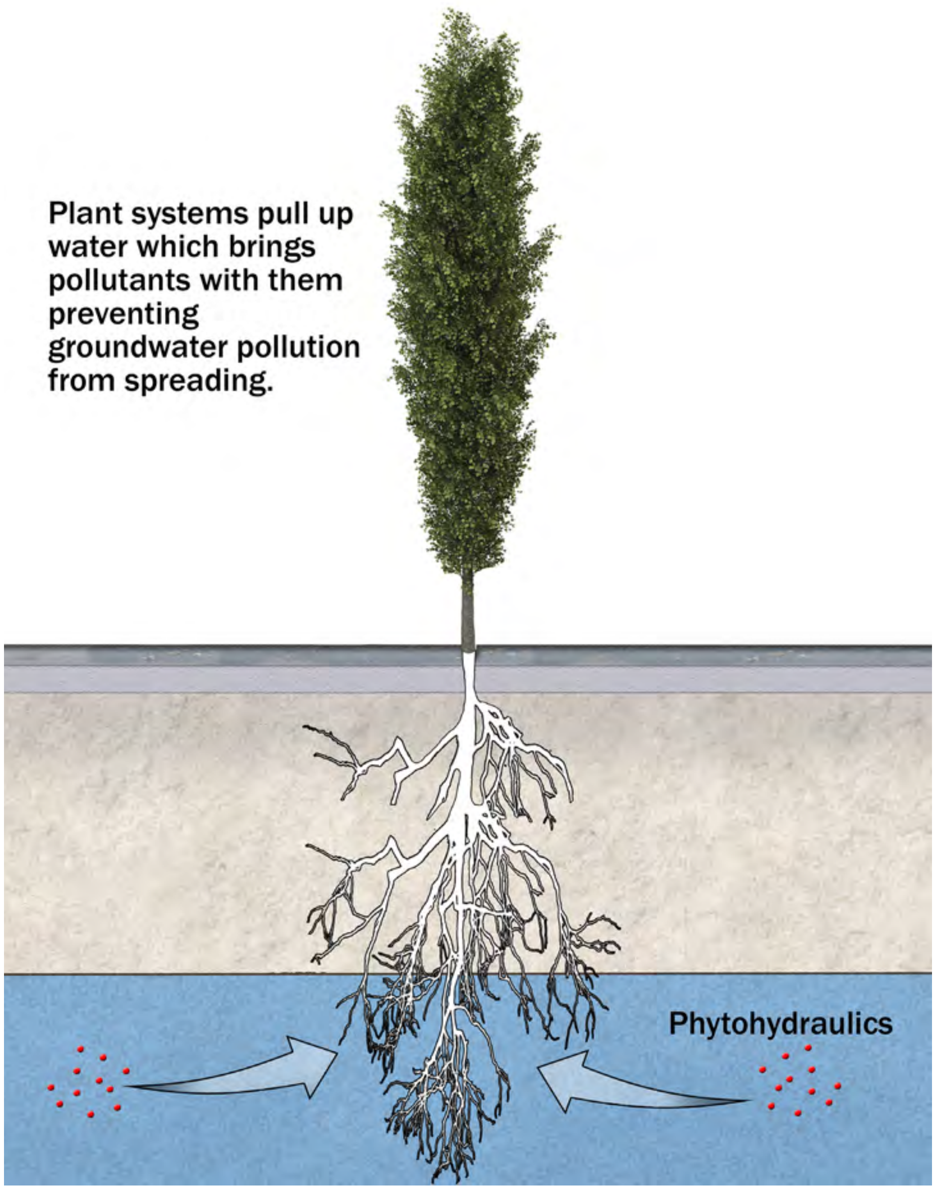



Figure 2.3 Phytohydraulics

on the directional flow of groundwater. If contaminants enter the groundwater they will diffuse creating a plume of pollution that moves as the water flows. By creating a force strong enough to uptake this flow it is possible to prevent the plume from migrating off site. Once a plume has been directed to a network of tree roots other mechanisms like phytodegradation and phytovolatilization will kick into action mitigating the contaminants.

**Phytostabilization** uses certain plant species to immobilize contaminants in the soil through absorption and accumulation by roots and prevents mobilization and migrating. This process is beneficial because it can be part of ecosystem restoration on the fringe area of sites that work to corral contaminants leaking off site. Unfortunately, this method requires constant monitoring and some levels of toxicity may prevent plants from growing.

**Phytovolatilization** (Figure 2.4 on following page) is the use of plants to volatilize pollutants from soil or polluted ground waters and release them into the atmosphere as safer compounds (Westphal and Isebrands 2001). The release of the gas that is usually slowly enough and do not impact the air quality significantly. The negatives associated with this method include its capacity for only lower contaminant concentrations and the possibility of the transpiration of harmful chemicals that could return to the surface during precipitation.

**Phytoextraction** uses pollutant accumulating plants to remove metals or organics from the soil by concentrating them into harvestable plants biomass. These plants can then be harvested and incinerated with the ability to capture the energy during the burning process. This process is beneficial because of its low costs and ability to remove some of the most harmful contaminants from the soil. The downside is the length of time it takes to fulfill full decontamination of the soil. When organic contaminants are coupled with phytodegradation and phytometabolism it is possible to completely remove the contaminant from the site. If a plant is capable of storing inorganic contaminants like zinc, cadmium, copper it becomes impossible to degrade them any further as they are in their most basic states. A plant cannot use these and therefore not rid them from the environment, but they can hold them in place and prevent them from moving off site into a more vital area of the landscape. By extracting them and holding them in place within its shoots and leaves a plant can then be removed from the site and transported elsewhere to deal with the inorganic contaminants. These contaminants can then be disposed of, burned or put through a process known as phytomining where the metals are extracted and reused.

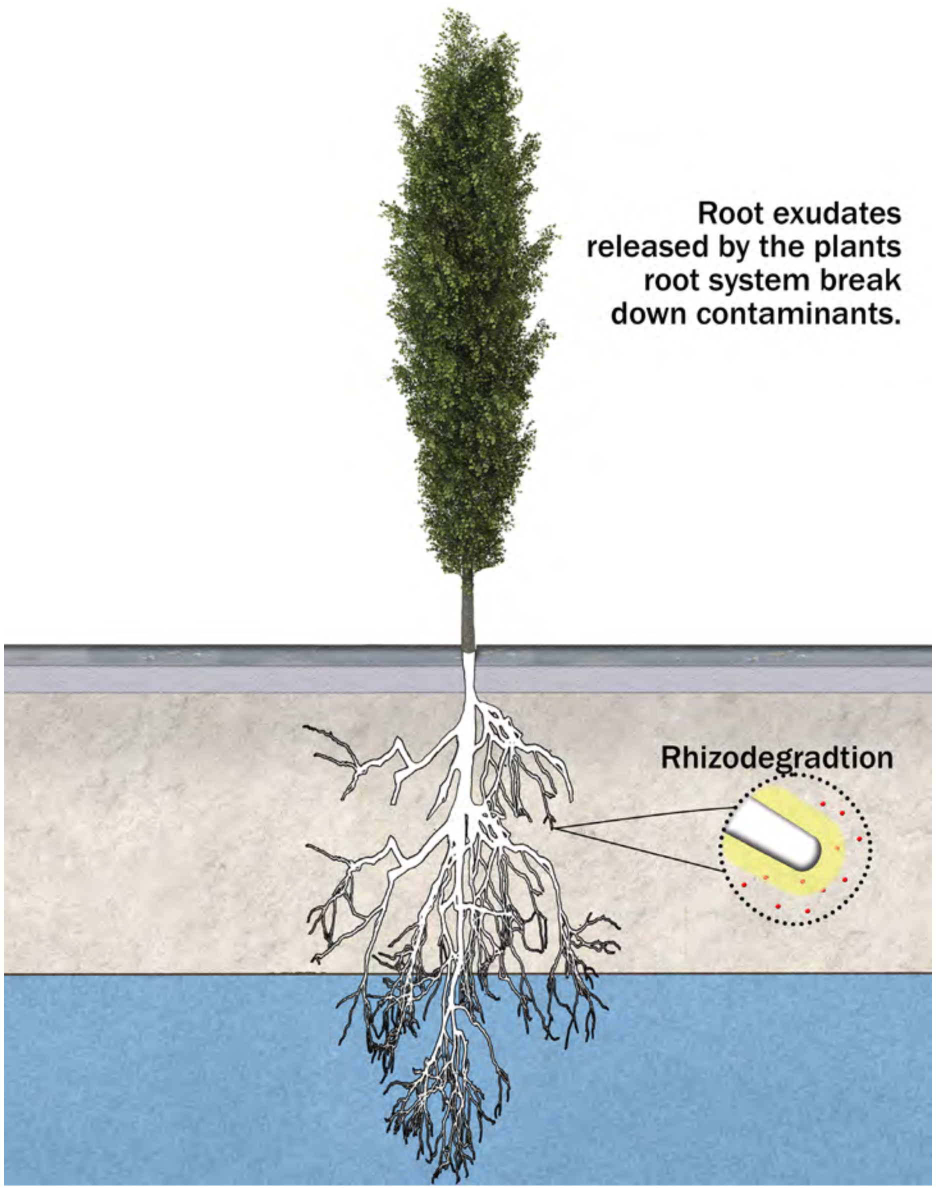



Figure 2.4 Phytovolatilization

**Phytometabolism** or **Phytotransformation** is a process by which plants can detoxify or store organic compounds that enter tissues. As organic contaminants are broken down into simpler parts such as nitrogen, phosphorous or potassium a plant can use them during its growth process as these are vital elements in vegetative growth. This can also be the case for organic contaminants that have been broken down by a plant through phytodegradation and further being phytometabolized and incorporated in the plants. These processes are commonly called the "green-liver" model (Burken 2003) because plant metabolism of organic compounds shares many processes with mammalian liver function with the exception of storage as opposed to excretion.

**Rhizofiltration** is applicable to constructed wetlands and stormwater filters and has become common practice in water and sewage management. The roots filter out pollutants and nutrients from the water. Rhizofiltration and phytoextraction are similar mechanisms that store organic or inorganic matter in their biomass. While rhizofiltration is used for treatment in aquatic environments, phytoextraction deals with soil remediation.

### Suitable Plants for Phytoremediation

Although different, each process follows the similar natural process of water and chemical uptake wherein metabolism within the plant breaks down harmful pollutants and then releases innocuous forms of these chemicals back into the soil leading to contaminant loss (Pivetz 2001). Essentially, these plants become natural, solar-powered pump-and-treat systems for cleaning contaminated systems (Van 2008). To maximize the efficiency of phytoremediation, careful consideration must be placed on what types of vegetation are used as these are chosen based on a wide range of factors (Figure 2.5). First and foremost, plants must be

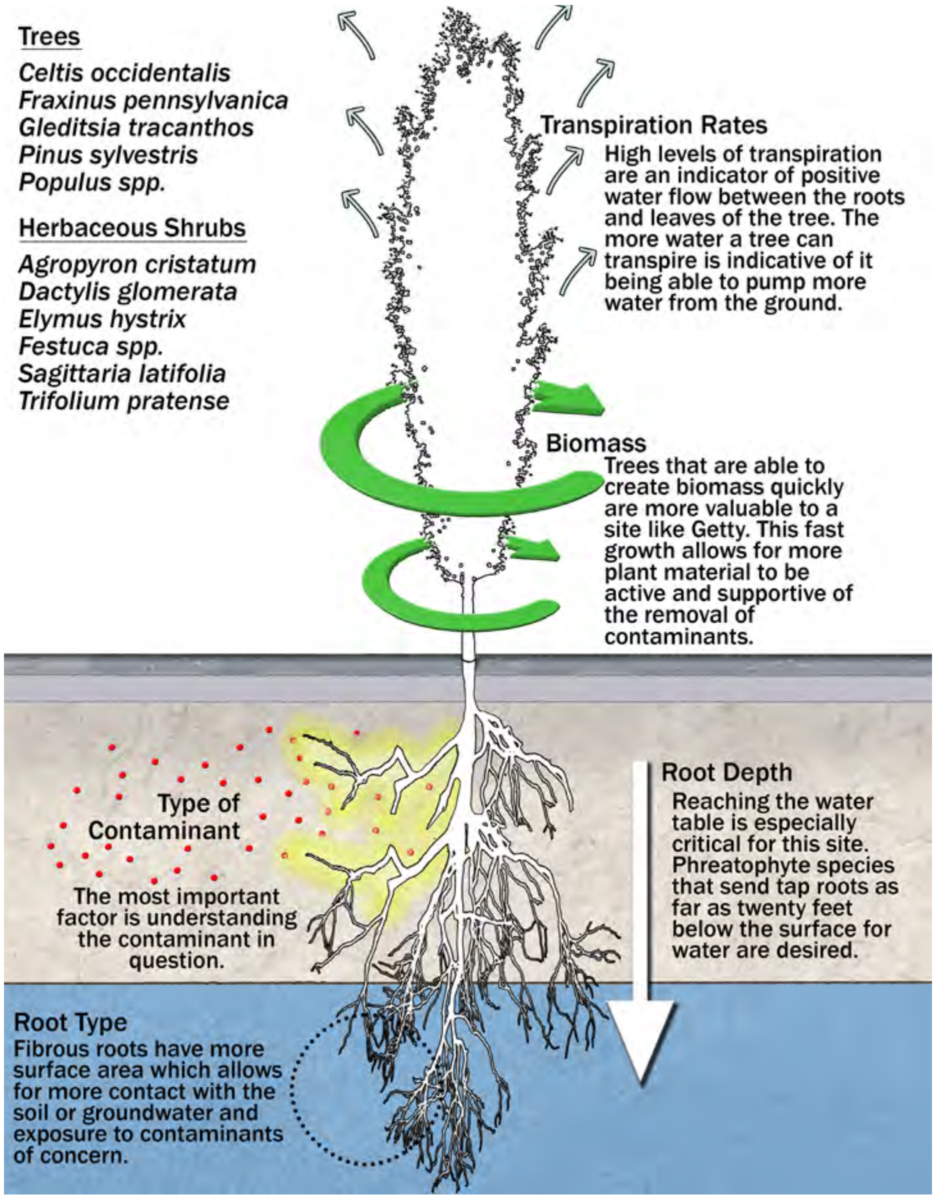



Figure 2.5 Factors of influence for plant selection

prescribed based on their ability to tolerate the pollutant present. Ideal plants have many and/or deep roots that pump enormous quantities of water during the growing season (Westphal and Isebrands 2001). Root systems that are fibrous (including many small to tiny roots) are favorable as well. These roots provide more surface area which allows for more contact with the soil and contaminants. This pumping results, subsequently, in high transpiration rates as that water is expelled into the atmosphere. This pumping and transpiration quality of a successful plant works because it promotes higher levels of pollutant removal in the groundwater. Plants with a high biomass are also favorable as they are capable of a higher work load.

Many articles have purported the consideration that Poplars (Populus spp.) and Willows (Salix spp.) are the most appropriate species for phytoremediation (Westphal and Isebrands 2001; Kang 2014; Kennen and Kirkwood 2015; Licht and Isebrands 2005). This is due to the rapid growth, deep and numerous roots, and ability for these species to take up large quantities of water (Westphal and Isebrands 2001). Other plant species are also favorable including: Eastern Cottonwood (Populus deltoides) and Red Mulberry Tree (Morus rubra).

Herbaceous shrubs like those mentioned in Figure 2.5 are also beneficial for phytoremediation. Many of these species are well adapted at surviving in hostile environments similar to urban conditions. They follow the same characteristics and preferences as trees.

Many deep rooted grass species (Kennen and Kirkwood 2015) also provide a service that can be beneficial in contaminations involving TPH and PAHs that stick to soils closer to the surface (Kennen and Kirkwood 2015). Given the great number of species available for phytoremediation, a relatively limited number of plants have been investigated pointing to a gap in the knowledge of this process (Pivetz 2001 ).

## Phytotypologies and Plant Selection

To most effectively target pollutants at a given location, a prescribed collection of plants should be administered with specific intent based on phytotechnology functions and determined remediation goals. Gathering a collection of phytotechnology plantings to perform deliberate and unique functions in these settings forms what is known as phytotypologies. Phytotypologies are a way to organize approaches to remediation in easy to understand and accessible ways. Essentially, Kennen and Kirkwood 2015 created a toolbox for fixing a contaminated site. Eighteen phytotypologies are introduced in this literature and each one serves a specific role in the landscape depending on the primary mechanism at work (phytotechnology), the location of the contaminant (soil, groundwater, wastewater, air), and the contaminant that is being addressed. Different phytotypologies can be combined with each other if the situation needs it or they can be integrated with non-remediation planting methods to create a balance of form and function within the landscape. In this way a site with a complex pattern of contamination can be treated with a variety of methods to better incite remediation.

Six out of eighteen phytotypologies described by Kennen and Kirkwood (2015) were selected for redesigning gas stations through phytotechnologies. Table 1 lists phytotypologies and relevant phytotechnologies, contaminant targeted and contaminant subject, and suitable plants.

| Phytotypology | Phytotechnology | Contaminant Targeted |
|---|---|---|
| Phytoirrigation | Rhizodegradation<br>Phytodegradation<br>Phytovolatization | Petroleum, Chlorinated Solvents, Nutrients |
| Interception Hedgerow | Rhizodegradation<br>Phytodegradation<br>Phytovolatization<br>Phytohydraulics<br>Phytometabolism | Petroleum, Chlorinated Solvents |
| Degradation Hedge/Living Fence | Rhizodegradation<br>Phytodegradation<br>Phytovolatilization<br>Phytometabolism | Petroleum, Chlorinated Solvents |
| Degradation Bosque | Rhizodegradation<br>Phytodegradation<br>Phytovolatilization<br>Phytometabolism | Petroleum, Chlorinated Solvents, Nutrients |
| Degradation Cover | Rhizodegradation<br>Phytodegradation<br>Phytovolatilization<br>Phytometabolism | Petroleum |
| Stormwater Filter | Rhizofiltration | Petroleum, Chlorinated Solvents, Nutrients |

| Contaminant Subject | Time Frame | Plants Acceptable | Notes |
|---|---|---|---|
| Wastewater or Groundwater | 3-10 years | Petroleum Tolerant/Chlorinated Solvent Tolerant.<br>Plants that grow fast with high evapotranspiration rates | Polluted groundwater at gas stations can be pumped up and irrigated onto gas station plantings targeted to degrade contaminant with solar powered pumps. Subsurface drip irrigation to avoid washing on to surface. Used for groundwater plumes. Mainly for nutrients. Seasonal use. |
| Groundwater | 3-10 years | Phreatophyte Species. High evapotranspiration rates and petroleum degrading. | Downgradient of LUSTs and auto-repair service bays. Interception hedgerows can be created to degrade gasoline in groundwater. Limited by narrow conditions and may not degrade all contaminants. Single row of tap trees tap into the water and assist in contaminant degradation. |
| Surface Soils (0-4 feet) | 0-5 Lighter Fractions<br>5-20+ Heavier Fractions | Petroleum Tolerant/Chlorinated Solvent Tolerant.<br>Plants that grow fast with high evapotranspiration rates | Shrub species are planted to degrade contaminants in soil up to 4 feet deep. Similar to degradation bosque, main difference is depth. Living fence is utilized to create boundaries between gardens. Almost always willow species. Used for aesthetic and screening purposes. Perimeter of gas stations. Mixed species can be considered to provide ecological function such as habitat and wildlife corridors. Layering with interception hedgerows and other typologies. |
| Soils (0-10 feet) | 0-5 Lighter Fractions<br>5-20+ Heavier Fractions | Petroleum Tolerant/Chlorinated Solvent Tolerant.<br>Plants that grow fast with high evapotranspiration rates | Installed around transfer points to break down freshly spilled fuel before it contaminates groundwater. Deep rooted trees and shrubs species degrade contamination areas within soil profile. Can be used in cleaning petroleum, chlorinated solvent spills deep in soils which have not yet migrated to groundwater. LUSTs before groundwater exposure. Addition of amendments to soil to aid plant establishment. |
| Soil (0-5 feet) | 0-5 Lighter Fractions<br>5-20+ Heavier Fractions | Deep rooted drought tolerant prairie grass species are often utilized. Mixed species are best. | Fuel spills washed into adjacent landscape areas can be broken down with targeted plantings. Many ornamental plantings (grasses) with large root systems and petroleum degradation capabilities can create attractive entry landscapes. Vegetation must be thickly planted and maintained with no visible mulch to maximum root-zone coverage. |
| Stormwater | 0-5 Lighter Fractions<br>5-20+ Heavier Fractions | Plants that thrive with substantial water. | Stormwater filters can be installed down grade of impervious surfaces to remove pollutants. Bioswale. TraditiB4:G9onal grey infrastructure techniques are paired to maximize treatment. |

### Phytoirrigation

The first to be discussed is phytoirrigation. This is a method of retrieving polluted groundwater, particularly from subsurface contamination plumes, and pumping it to the surface to be reused for irrigation. This form of phytotypology is beneficial on several levels as it addresses the concerns of contamination plumes while also preventing the need for excessive freshwater irrigation. To be done correctly, Kennen and Kirkwood (2015) have suggested that this form of irrigation be administered through a drip-irrigation system to prevent the release of contaminants above the surface where they can be hazardous to site visitors or wildlife. After the contaminants are pumped to the surface and released through the drip system they can begin to come in contact with the plantings root zones. At this point several of the previously discussed phytotechnologies begin. Phytodegradation, rhizodegradation, and phytovolitilization are the primary mechanisms at work during phytoirrigation at an abandoned gas station site where petroleum is the primary concern. To ensure the most effective and successful outcome for phytoirrigation the plants used must be considered. First and foremost the selection must be petroleum tolerant (Tables 2.1 and 2.2). Secondly, a plant with a high evapotranspiration rate and quick growth is crucial for success as this is indicative of plant material that is absorbing and processing water quickly and efficiently.

### Interception Hedgerow

Another method of targeting contaminated groundwater is an interception hedgerow. This treatment is especially important at gas stations as the limited amount of space typically available creates the needs for efficient plantings. To create an interception hedgerow a single row of trees is planted, usually around the perimeter of a site and downgradient of the source of the contamination, which will serve as a last line of defense for contaminated groundwater leaching offsite. Understanding the site is vital for this treatment as one must determine the depth of the pollutants in order to select plant types appropriately. Pollutants as deep as 20 feet may be targeted with tree species known as phreatophytes. Phreatophytes are plants that are especially adept at seeking groundwater as they send root systems much deeper than most typical tree species. By knowing the depth of the groundwater to be targeted one will better visualize the subterranean network to be created for mitigating contaminants. Naturally, the plant species chosen must also be capable of degrading the contaminant targeted and as with phytoirrigation it is petroleum that is to be targeted at gas stations. The primary mechanisms at work in this implementation are rhizodegradation,phytodegradation,phytovolatilization, phytohydraulics and phytometabolism.

As these hedgerows are implemented, on the perimeter of sites, they can serve as a buffer for contaminants as much as they can serve as a visual or aesthetic buffer. Creating a strong visual for a site that was chosen for its visibility as many gas stations were is a preferred treatment to draw interest and prevent further eyesores. To further invoke a display of aesthetic merging with functional mitigation the interception hedgerow can be layered with other phytotypologies that will be introduced shortly. This allows for a full display of the functions and adds interest to all parts of the site.

### Degradation Hedge/Living Fence

Similar to interception hedgerows, degradation hedges and living fences are valuable methods of targeting contaminants in areas where space is limited, specifically on the edges of sites and in areas where definition of space is needed. Where these two methods vary is the type of species planted and what depth they target. Whereas interception hedgerows utilize trees with deep rooted phreatophyte species, degradation hedges use shrub and grass species that are intended on targeting surface soils up to four feet deep. These species are typically prairie grasses which have root systems that plunge deep below the surface and have high surface fibrous root systems. In nature these species exist in dry prairie conditions and must go below the surface with these root systems to find water. This gives them the intrinsic ability to seek out water that is

| Petroleum Degradation Plants | Latin Name | Common Name | Category Targeted | Contaminant | Native to MA |
|---|---|---|---|---|---|
| Trees | Acer platanoides | Norway Maple | Easy | BTEX | |
| | Betula pendula | European White Birch | Hard | PAH | |
| | Celtis occidentalis | Hackberry | Both | BTEX, TPH, PAH | X |
| | Fraxinus pennsylvanica | Green Ash | Hard | PAH | X |
| | Gleditsia triacanthos | Honey Locust | Easy | BTEX | X |
| | Juniperus virginiana | Eastern Red Cedar | Easy | BTEX | X |
| | Morus alba | White Mulberry | Hard | PAH | |
| | Morus rubra | Red Mulberry | Hard | PAH | X |
| | Pinus banksiana | Jack Pine | Easy | BTEX | X |
| | Pinus sylvestris | Scots Pine | Both | TPH | |
| | Populus nigra var. italica | Black, Lombardy Poplar | Both | PAH | |
| | Populus spp. deltoides | Poplar species and hybrids | Both | Varies | |
| | Quercus macrocarpa | Bur Oak | Easy | BTEX | X |
| | Robinia pseudocacia | Black Locust | Both | PAH, MOH | X |
| | Salix alba | White willow | Easy | BTEX | |
| | Salix nigra | Black Willow | Both | PAH, BTEX, TPH | X |
| | Salix spp. | Willow | Both | TPH, BTEX, PAH | |
| | Ulmus parvifolia | Chinese Elm | Both | Dioxene | |

Table 2.1 Shows tree species tolerant of petroleum related pollution

contaminated and bringing it into its system and mitigating it, which is what is wanted in a petroleum degrading plant. The degradation hedge method utilizes rhizodegradation, phytodegradation, phytovolatilization and phytometabolism mechanisms for degrading petroleum and chlorinated solvent contaminants. The different forms create a n o pportunity for layering degradation hedges and interception hedgerows o n t he edges o f sites to further implement a barrier that prevents contamination l eaching offsite. Pragmatically it fulfills a best possible scenario for preventing leaching, while aesthetically it is capable of expanding the narrative that the phyto-process can be beautiful and functional simultaneously. These walls can either aid in blocking undesirable views into or out of the site by limiting viewsheds while also being capable of serving as a facilitator for visual or physical movement by visitors.

#### Degradation Bosque

Degradation bosques may very well be the poster child for phytoremediation. Essentially a degradation bosque is very similar to an interception hedgerow if the hedgerow was expanded into a grid of trees as expansive as several acres or as small as a 2x2 pattern within the confines of an abandoned gas station. This method of contamination targeting uses deep-rooted tree and shrub species to target petroleum and chlorinated solvent contaminants deep into soils from depths of zero to ten feet. The main purpose of creating a grid of trees is efficiency and overlap. By creating a grid of trees you are maximizing the effectiveness by ensuring that every available portion of the land being planted is targeted. The strength in the grid is under the surface where the root systems of these trees become interconnected and are essentially in contact with every cubic foot of soil where the root zone lies. This is

| Petroleum Degradation Plants | Latin Name | Common Name | Category Targeted | Contaminant | Native to MA |
|---|---|---|---|---|---|
| Shrubs/Grass | Agropyron cristatum | Crested Wheatgrass | Both | TPH | |
| | Andropogon gerardii | Big Bluestem | Hard | PAH | X |
| | Avena sativa | Oat | Both | TPH | |
| | Bouteloua curtipendula | Side Oats Grass | Both | TPH, PAH | X |
| | Bouteloua dactyloides | Buffalo Grass | Both | TPH, PAH | X |
| | Bouteloua decumbens | Signal Grass | Hard | PAH | X |
| | Bromus inermis | Smooth Brome | Both | TPH | |
| | Carex cephalophora | Ovalhead sedge | Hard | PAH | X |
| | Carex stricta | Sedge | Both | TPH | X |
| | Cercis canadensis | Eastern Redbud | Hard | PAH | X |
| | Elymus canadensis | Canadian Wild-Rye | Hard | TPH, PAH | X |
| | Elymus hystrix | Bottlebrush Grass | Hard | PAH | X |
| | Elytigria repens | Couch Grass | Both | TPH | |
| | Festuca spp. | Festuca | Both | TPH, PAH, BTEX | |
| | Festuca arundinacea | Tall Fescue | Both | TPH, PAH | |
| | Festuca pratensis | Meadow Fescue | Both | TPH | |
| | Festuca Rubra | Red Fescue | Both | TPH, PAH | X |
| | Geranium viscosissimum | Sticky Geranium | Hard | PAH | |
| | elymus angustus | Altai Wildrye | Both | TPH | |
| | Linum usitatissimum L. | Flax | Both | TPH | |
| | Lolium multiflorum | Annual Rye | Both | TPH, PAH | |
| | Lolium perenne | Herbaceous Ryegrass | Both | TPH, PAH, BTEX | |
| | Lotus corniculatus | Birdsfoot Trefoil | Both | TPH, PAH | |
| | Medicago sativa | Alfalfa | Both | TPH, PAH, Benzene | |
| | Melilotus officinalus | Sweet Clover | Both | TPH, PAH | |
| | Miscanthus x giganteus | Giant Maiden Grass | Hard | PAH | |
| | Panicum virgatum | Switchgrass | Both | TPH, PAH | X |
| | Pascopyrum smithii | Western Wheatgrass | Both | TPH, PAH | X |
| | Phalaris arundinacea | Reed Canary Grass | Hard | PAH | |
| | Poa pratensis | Kentucky Bluegrass | Both | TPH, PAH, BTEX | |
| | Sagittaria latifolia | Arrowhead | Both | TPH | X |
| | Schizachyrium scoparium | Little Bluestem | Hard | PAH | X |
| | Secale cereale | Winter Rye | Both | TPH, PAH | |
| | Solidago spp. | Goldenrod | Both | TPH, PAH | X |
| | Sorghastrum nutans | Indiangrass | Both | TPH, PAH | X |
| | Spartina pectinata | Prairie Cordgrass | Hard | PAH | X |
| | Thinopyrum ponticum | Tall Wheatgrass | Both | TPH | |
| | Trifolium spp. | Clover | Both | TPH, PAH, BTEX | |

Table 2.2 Shows shrub and grass species tolerant of petroleum related pollution

important because it provides constant layers of activity, contrary to the interception hedgerow which has only one layer. It is also desirable because in this type of activity it is not uncommon for a tree to die and leave a gap in the grid. While this could be much more problematic in a row of trees, it is much less concerning when there are multiple rows there to provide backup and support. The primary mechanisms at work in a degradation bosque are rhizodegradation, phytodegradation, phytovolatilization and phytometabolism.

### Degradation Cover

Degradation cover is very similar to a degradation hedge. As with the similarities between degradation bosques and interception hedgerows, degradation covers are essentially a more expansive version of degradation hedges. This application uses thick, deep rooted shrub and grass species to target soils from zero to five feet deep. The predominant plants used for degradation cover are the same deep rooted and drought tolerant prairie grass species mentioned with degradation hedges. The fibrous root zones in these plants are perfect for targeting localized spills and surface leakage. This is because localized spills and leakage at gas stations is very common as a result of transfer errors when new gasoline is being delivered or when individuals accidentally release gas onto the surface while pumping. The results of these errors is contamination found in the upper portions of the soil where these plant species perform. The mechanisms at work for this treatment are rhizodegradation, phytodegradation, phytovolatilization and phytometabolism.

### Stormwater Filter

As the name suggests stormwater filters are solutions to polluted stormwater. These applications generally consist of plantings that tolerate an extreme amount of water as they are placed down gradient of impervious surfaces and are intended on collecting contaminants as they are washed off of those surfaces. As stormwater flows off of impervious surfaces and make their way to stormwater filters the contaminants on the surface are picked up and washed away with them. Upon reaching the stormwater filter the contaminants are then removed and immobilized by the plant material. The purpose of this is to prevent the contamination from reaching the groundwater or moving offsite.

Once they are held in the filter the contaminants can experience a variety of different outcomes. Degradation, as discussed among many other phytotypology methods, is one option for organic contaminants like petroleum and chlorinated solvents. To maximize this particular outcome a diverse selection of plant material that breaks down petroleum and produces high biomass is suggested. This will allow for a mixture of root types to target the contamination while having the capacity necessary for high rainfall events. If the target contaminant is inorganic, then another option would be stabilization focused. In this method the contaminants are held in the soil and root system like a sponge and while they are not degraded they are prevented from leaching off site. If this is the direction taken and it is necessary to remove the contaminants from the soil then the plant species will need to be harvested.

Stormwater filters can provide a buffer between existing roads and abandoned gas stations to prevent any further contamination from accessing the site. This also creates an opportunity for treating the polluted roadway water which can do multiple tasks at once. For one it can limit the amount of pollution entering the groundwater and further landscapes. Also, it can promote this method of treatment as an acceptable means to the public. By letting a site under remediation take on another level of duty the site can then be lauded for that extra contribution. In the case for this project, accepting rainwater from adjacent roadways onto the abandoned gas station site also serves as another means of education and experimentation. When part of the goal is engaging public interest and proving these methods this could go a long way in publicity.

### Multi-Mechanism Buffer

The primary goal of applying phytotypology methods is to provide the maximum amount of phytotechnology benefits in the smallest area. To do this one can take any of the previously explained typologies and begin layering them where possible to create a multi-mechanism buffer. This method is primarily beneficial because it can allow for several different methods of targeting in the same area while providing the flexibility to serve aesthetic appeal to the community. Rather than applying a single typology to each location the method of layering and combining can begin to naturalize the landscape rather than use it in a servile manner through applications of these processes. The range of benefits in a multi-mechanism buffer are broad as it provides a large amount of ecosystem services. Kennen and Kirkwood 2015 make note of these and mention erosion prevention, wildlife habitat and corridors, carbon sequestration, real estate value increases, enhancement of recreational and aesthetic value as well as the ability to remove contamination.

# METHODS

# Methods

This project applied a mixed method containing a review of relevant literature on urban brownfield remediation and their potential for providing ecosystem services and new green spaces, the problem of abandoned gas stations in Northern America and their typical contaminants, and the study of phytotechnologies as an inclusive approach of applying phytoremediation. Eighteen phytotypologies after Kennen and Kirkwood (2015) were studied. Nine of these typologies were recommended for the remediation of gas stations and studied in more detail and in relationship to the specific climatic conditions of the case study; six were finally selected and explored with other design strategies common to landscape architecture at a real world location in Hadley, Ma. (Figure 3.1). Because actual borings could not be executed, the placement of contaminants was assumed in correspondence to the prevailing literature. In practice each brownfield must be assessed individually by soil specialists for the contaminants at present. Further methods that have been applied in the analysis are relevant to the profession of landscape architecture such as regional context including existing greenways and trails, watershed, land uses, traffic and walkability, and visual-spatial quality.

### Inventory and Analysis

During the inventory and analysis process of this project, information was gathered from various levels of scope and detail. It is imperative to view remediation sites from a macro and micro scale because the intricacies that occur within the site can have lasting impacts on adjacent land and the region as a whole. Understanding how the Getty site fits into the surrounding landscape and watershed was one of the most important parts of the inventory and analysis phase.

To do this an analysis was done from a regional perspective and a site level perspective. The regional analysis focused on soils, hydrology, land use, circulation and vegetation of a portion of Hadley, MA along Route 9 (Figure 3.2). This area lies between the larger townships of Amherst, MA to the East and Northampton, MA across the Connecticut River to the West. The site level analysis focused on those and more esoteric qualities, such as contaminants and contaminant locations within the property and surrounding property of the abandoned Getty gas station.

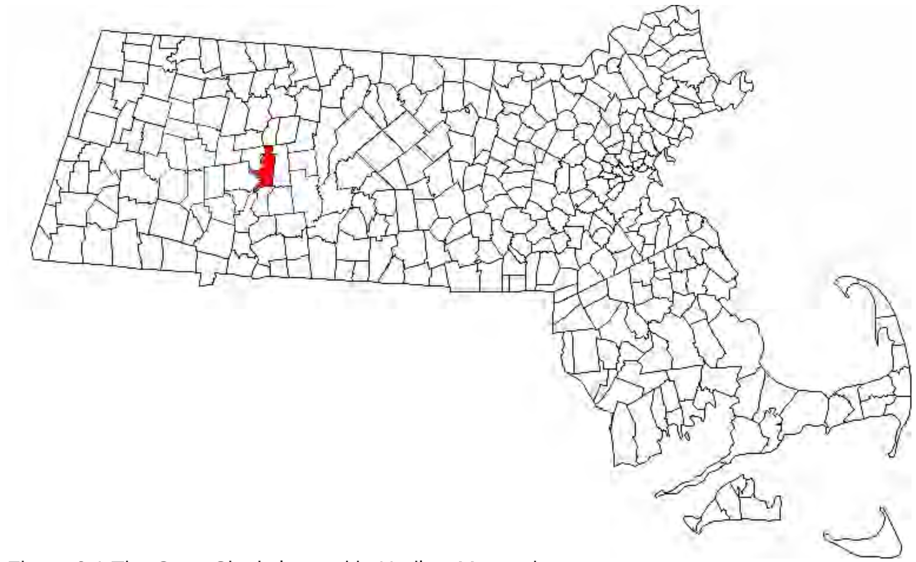


Figure 3.1 The Getty Site is located in Hadley, Massachusetts

### Regional Analysis

The following pages present several levels of regional analysis conducted at a scale that includes Northampton, the Connecticut River, Hadley and Amherst. These locations connect to each other through circulation, soil conditions and hydrology.

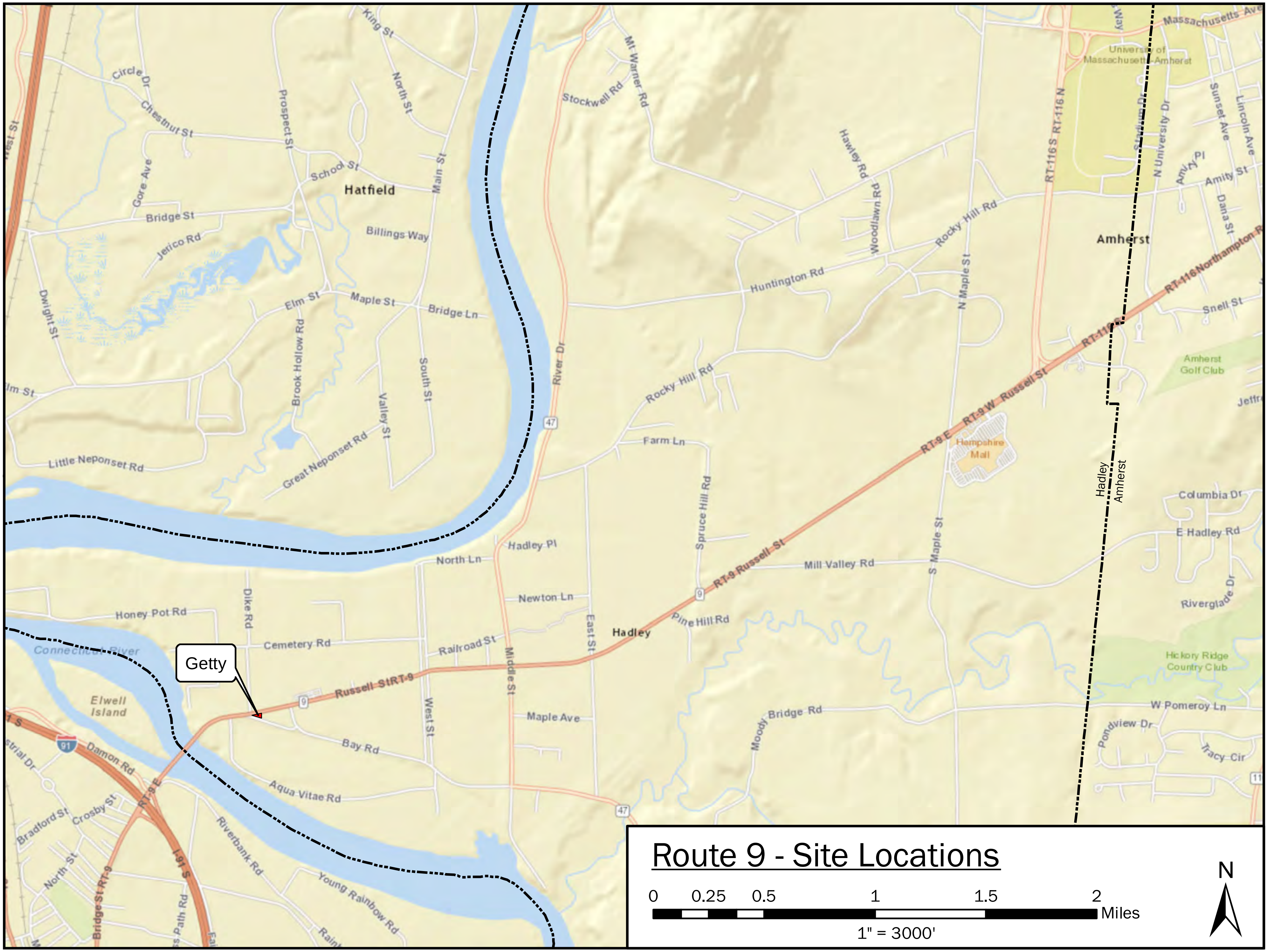



Figure 3.2 shows the Getty Site highlighted along Route 9. This road connects Amherst and Northampton.

## Circulation

Hadley, MA with a population of 5,250 (2010 Census) is primarily a rural farming community where the predominant land use is farmland. With no discernible town center, it serves as a conduit between Northampton with all of the interstate exit traffic and everything East of the Connecticut River, including Amherst. Amherst, with a population of 37,819 according to the 2010 census, is home to the University of Massachusetts, a large public university with an enrollment of 28,635, as well as, several other academic institutions, such as Amherst College. The jobs, academic opportunities and cultural significance of these colleges and universities creates a strong draw to this area from all surrounding cities in the Pioneer Valley and beyond that necessitates vehicular traffic from all directions. This is most evident from the traffic created along Route 9 where individuals are commuting back and forth across the Connecticut River.

There are two bridges that connect these sides, one is the Norwottuck Rail Trail, a dedicated pedestrian/bike path that utilizes an abandoned rail line, and the four-lane Calvin Coolidge Bridge which sees an average rate of nearly 34,000 cars a day (2002) when considering both directions of travel (MASSDOT). There is not another bridge crossing the Connecticut River until you reach Sunderland 12 miles to the North or Holyoke 11 miles to the South. This is one reason for such heavy traffic loads across these bridges as they serve as the only dedicated bike route in the area and the most convenient and direct way to access the interstate.

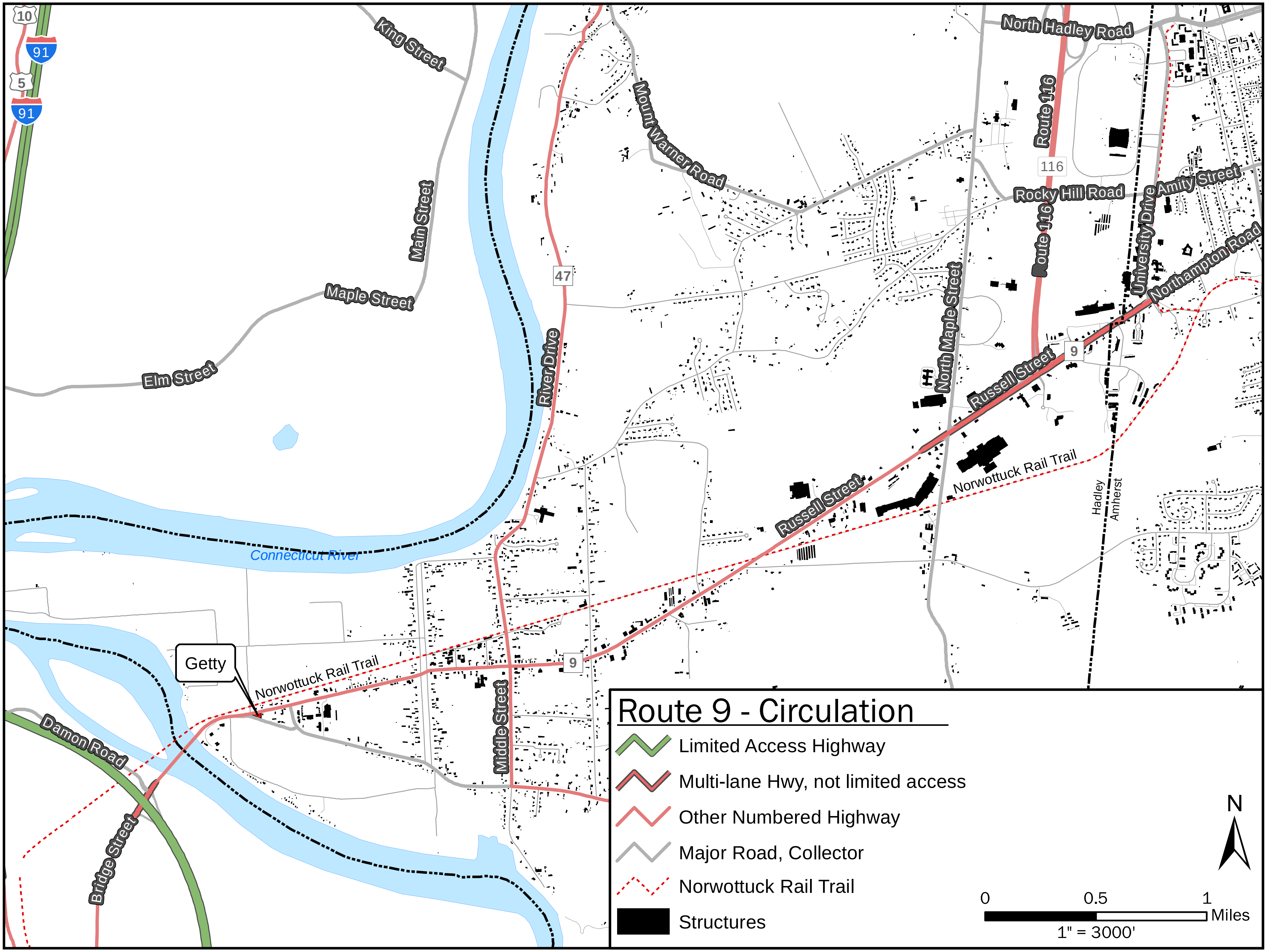



Figure 3.3 shows the prominence of the Getty Site as it is situated on a main corridor.

## Hydrology

The Pioneer Valley is drained predominantly by the Connecticut River as it is the primary tributary in this area. Hadley lies completely within the Connecticut River Watershed and this area utilizes its ability to irrigate and provide for the necessary industry present in the area. It is historically seen as the lifeblood of the farming community that the region still holds dearly today.

It can be seen how the Getty Site is located next to a marshland area that connects to the Connecticut River. This is the main concern when discussing the pollutants present. They are dangerously close to a waterway that this community relies on for farming. Considering the predominant form of farming in this area is organic, it is especially concerning to see the relation of waterway and abandoned gas station.

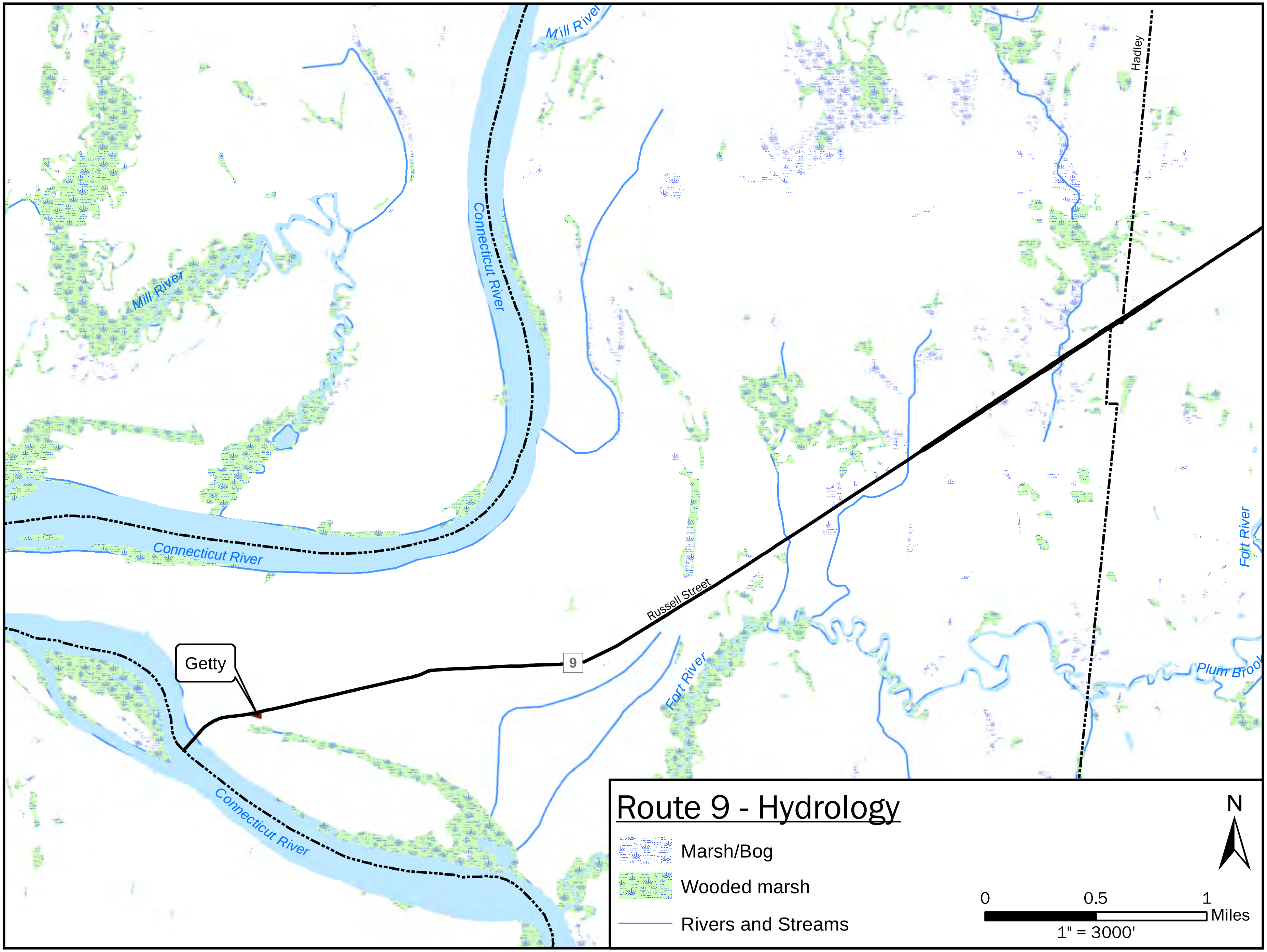



Figure 3.4 shows the proximity of the Getty Site to vital waterways

## Soils

The soils of the Pioneer Valley are especially suitable for growing crops. The prime soils are mostly made up of Hadley Silt Loam and Winooki Silt Loam. This has created a subculture of farming and organic farming in the region that is widely recognized outside of the valley. It is something that the community builds pride on and values greatly. These soils can be rich and fertile to great depths as silt loam is found 68 inches below the surface. The depth to water table ranges from 48 to 72 inches while the depth to any restrictive feature is more than 80 inches.

The Getty Site lies within these prime soils. Preventing further contamination of the surrounding soil is an issue worth achieving. Restoring the soil at the Getty Site to a state that is no longer contaminated would not only be a worthwhile expenditure, but would also send a message about how we treat such valuable lands for this community. Making a statement about brownfield cleanup in valuable lands is something that can be done moving forward.

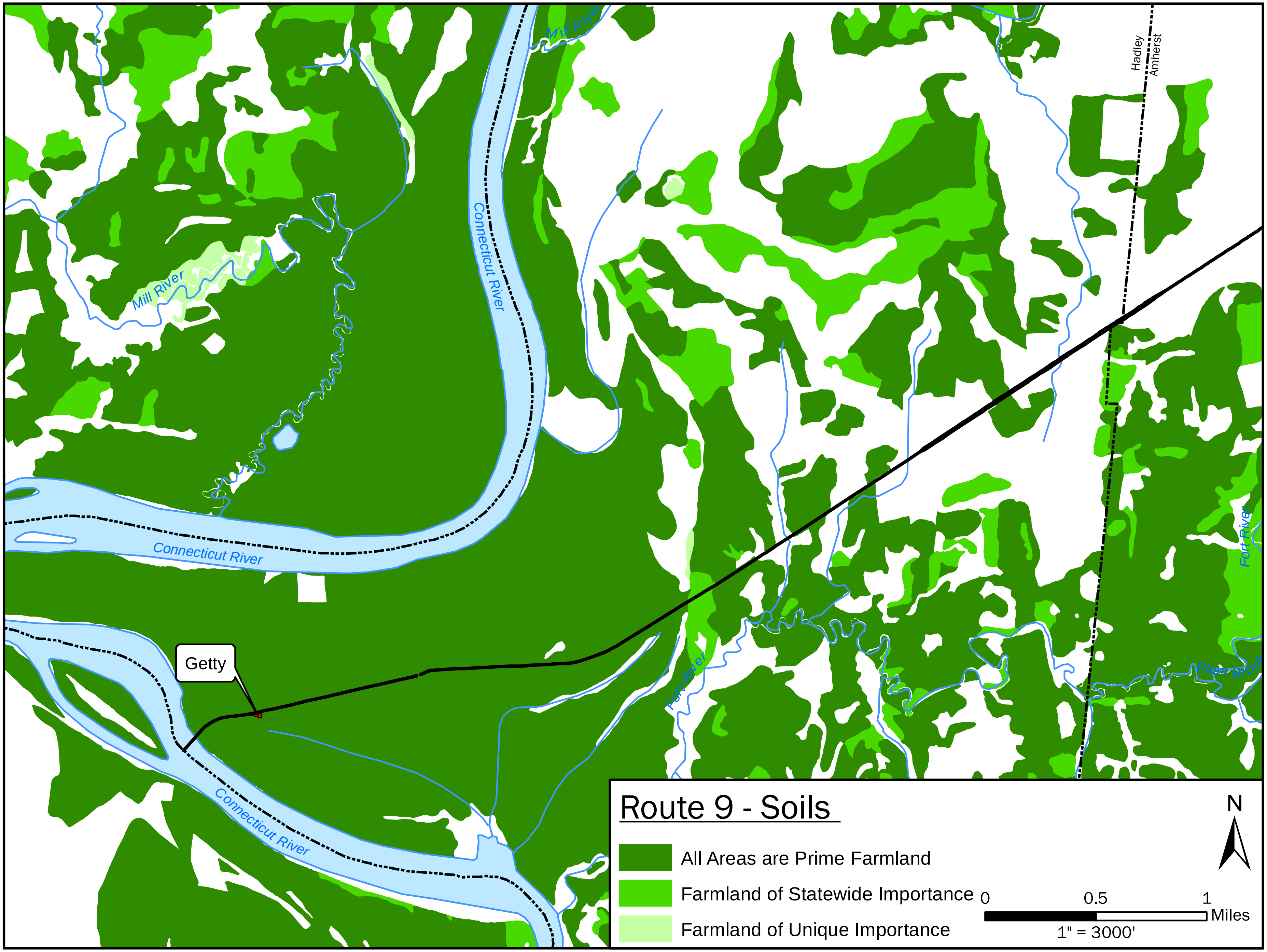



Figure 3.5 shows how fertile and valuable the soil is in relation to the Getty Site

## Site Specific Analysis

The following pages present several levels of site-specific analysis conducted at a scale that focuses on the Getty Site. T his includes circulation, l and u se, s oils, vegetation an d contamination. Following these analyses is further information regarding t he existing conditions of the Getty Site.

## Getty Circulation

It can be seen here how the Getty Site lies directly on Route 9 (Figure 3.6). This major four-lane road provides high visibility to the site. As of now this visibility portrays dereliction to t he vast amount of passersby. This provides an excellent opportunity to transform this site into something that can be seen as a beacon of sustainability for the community and a new step forward in maintaining what is valuable.

Bay Road (Figure 3.7) runs to the South of the Getty Site. Although it is seen as a mildly convenient shortcut for those traveling South, it could also be closed and utilized as a means of continuing bicycle and pedestrian traffic from the Norwottuck Rail Trail. This also provides an opportunity to buffer the marsh area that lies on the other side of Bay Road.

In Figure 3.8 the proximity of the Norwottuck Rail Trail becomes clear. The ability to connect this trail through the Getty Site is a clear opportunity for a new connection. As people travel from Northampton along this rail trail there is a disconnect heading South that could be fixed with a new system that is trailheaded at the Getty Site.

Figure 3.6 shows the buildup of traffic along Route 9

Figure 3.7 shows Bay Road looking South

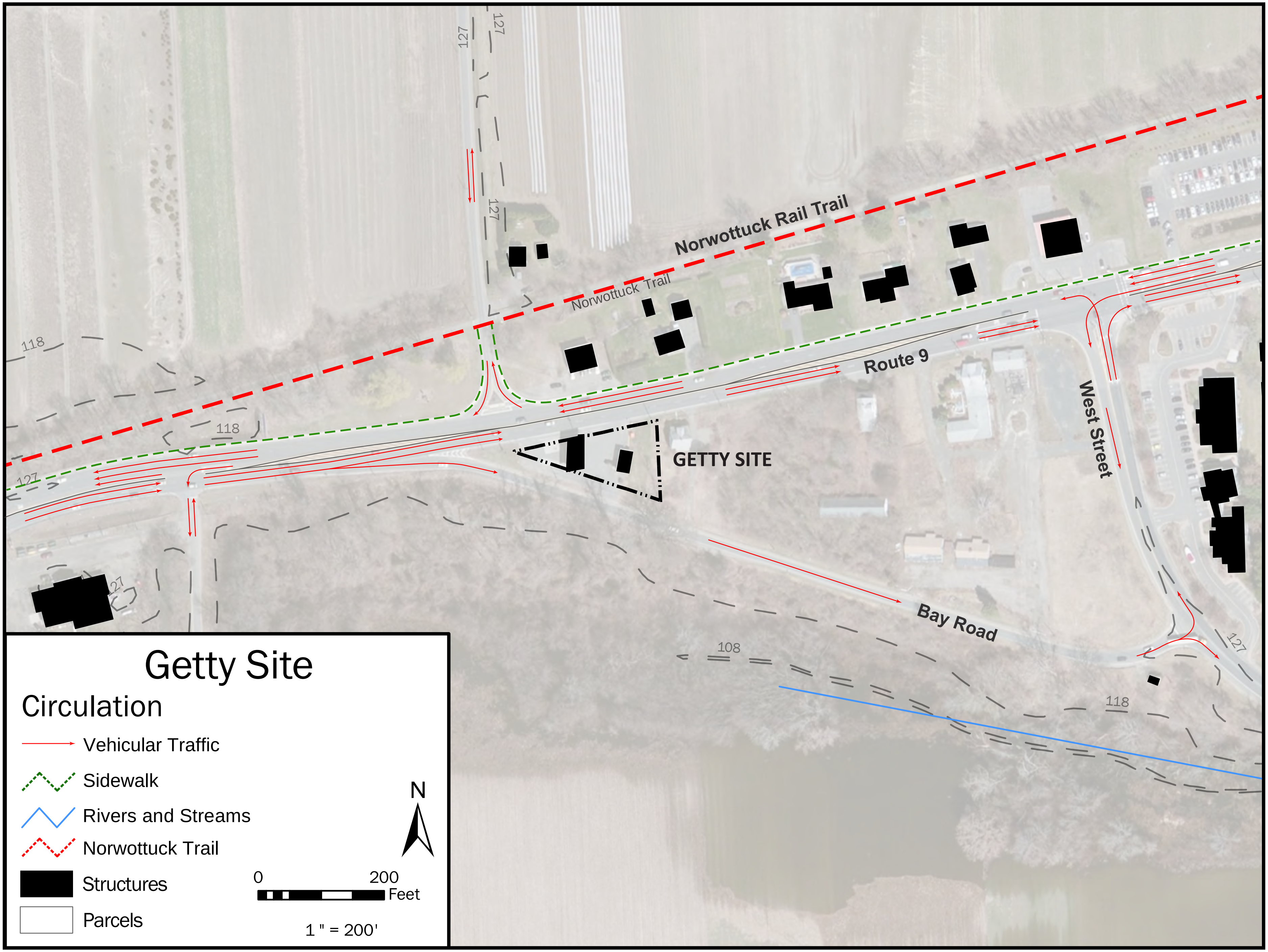



Figure 3.8 Circulation Map of the Getty Site

## Getty Land Use

The Getty Site is surrounded by light residential (Figure 3.9) and light commercial (Figure 3.10) land uses. As Route 9 is essentially a conduit between Northampton and Amherst, it usually has these land uses along its edges and no further. Beyond these land uses is typically agriculture.

Figure 3.9 shows residential land use beyond that has been recently demolished and removed


Figure 3.10 shows light commercial use across Route 9. Common for this road.

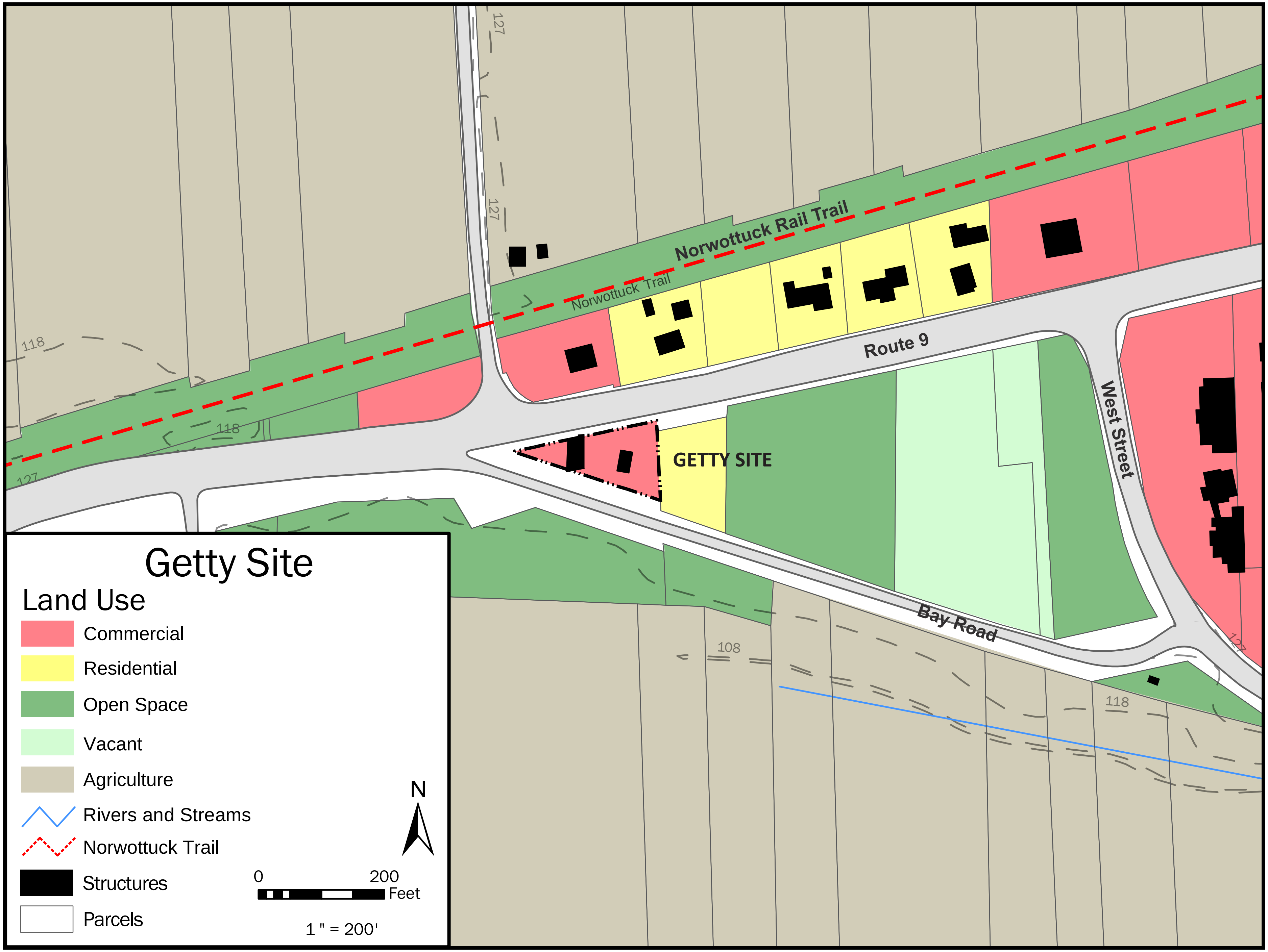



Figure 3.11 Land Use Map of the Getty Site

## Getty Soils

Beneath the Getty Site is predominantly Hadley silt loam as mentioned earlier. This fertile soil creates problems for contamination as it allows for high levels of percolation that can move contamination into the water table which would allow for more expedited movement towards the Connecticut River or elsewhere.

At many locations on the Getty Site there is exposed soil from asphalt and concrete removal (Figures 3.12 and 3.13). These areas were torn out to remove the underground storage tanks. The backfill that was dumped back in to these voids was likely some form of dense grade aggregate stone that is unnatural to the site.


Figure 3.12 shows exposed soil that is not native to the area

Figure 3.13 shows exposed soil not native to the area

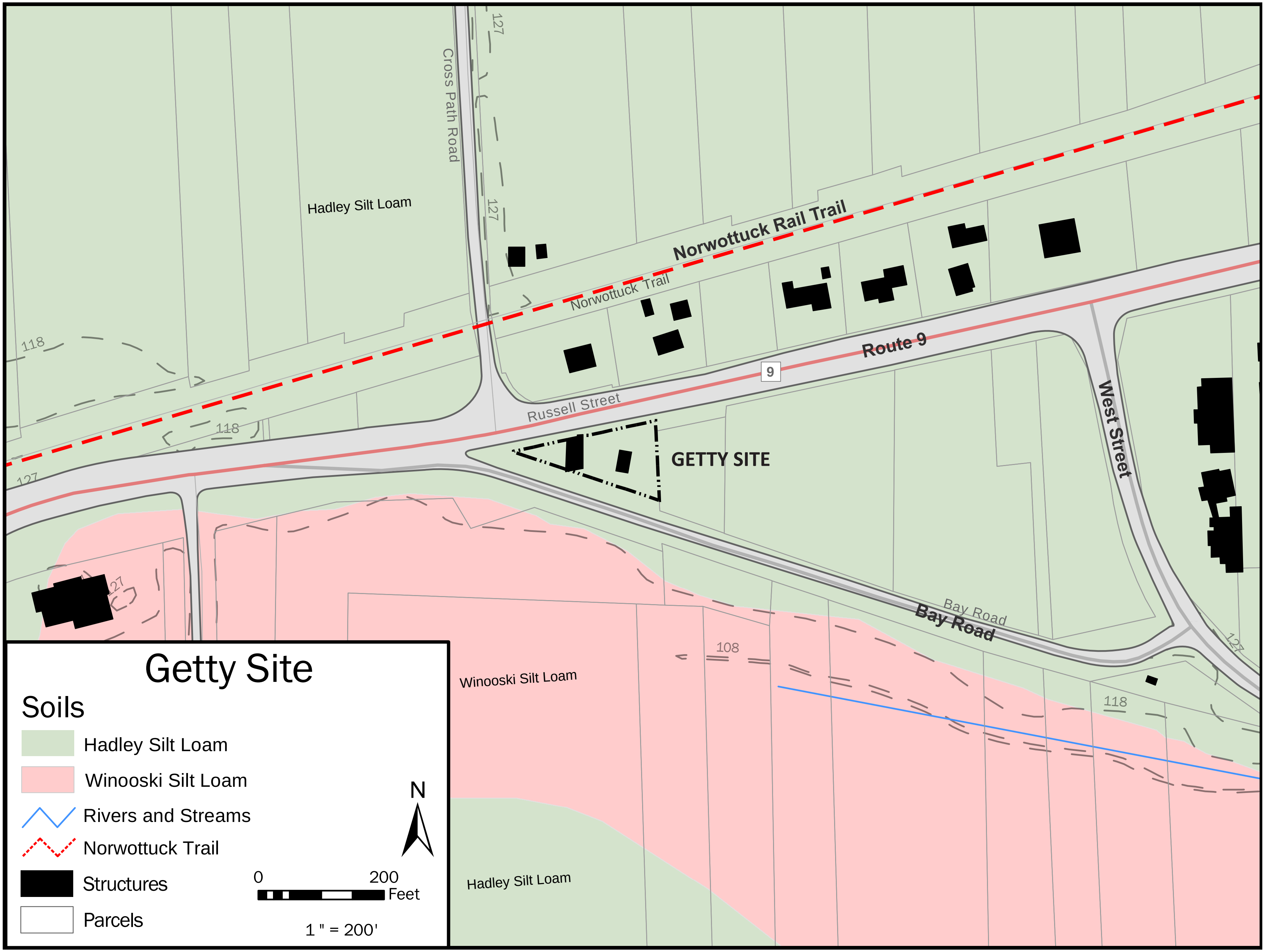



Figure 3.14 Soil Map of the Getty Site

## Getty Vegetation

The areas of permeability on the Getty site are made up of swaths of grass. They are limited to the edges of the site and are primarily for buffering the road and property lines. There are several areas where cracks in the existing asphalt and concrete have allowed for the growth of weedy plants like goldenrod and wild geranium. There is little to no vegetation on the site itself aside from weedy plants that are taking advantage of a dilapidated environment and growing in cracks in the pavement (Figure 3.15).

Toward the edge of the site adjacent to neighboring property there is a line of trees and hedges that screen the house residing there. Towards the South, across Bay Road, is a long stretch of forested area that continues for several hundred feet before opening into a large field used for farming (Figure 3.16). It is in this forested area that the concern over pollutants entering the Connecticut River arises as the area is home to the beginnings of a tributary that leads to it.

Figure 3.15 shows how vegetation proliferates naturally from the derelict site

Figure 3.16 shows the vegetation across Bay Road

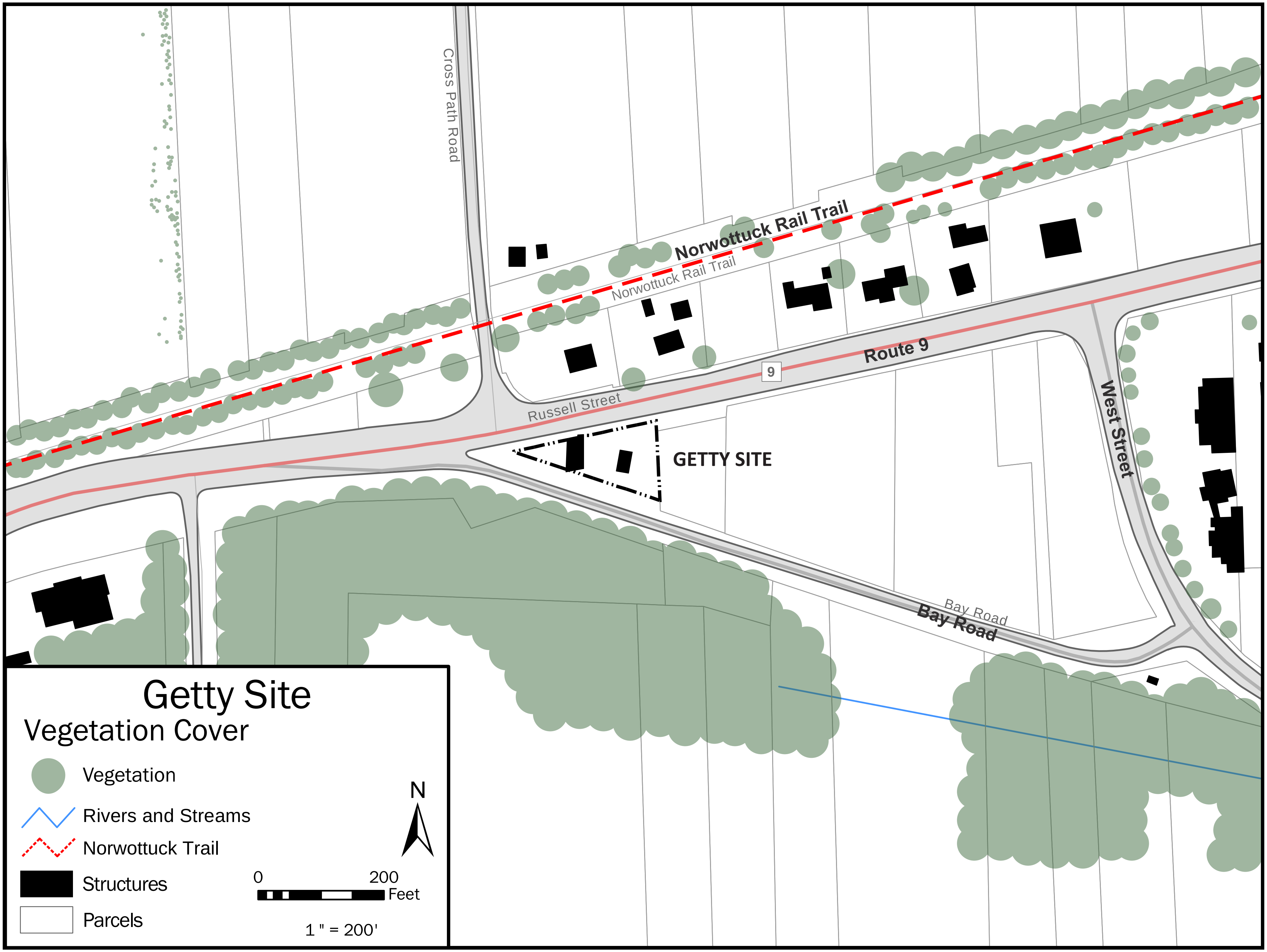



Figure 3.17 Vegetation Map of the Getty Site

## Getty Contamination

These contaminant qualities of the abandoned Getty gas station were developed and imposed on the site theoretically, as one could not retrieve core samples of the soil itself for testing. To do this research was done to determine the particular contaminant and likely locations that exists in common gas station remediation projects.

The outcome of this research can be seen in Figure 3.20. This figure shows the primary culprits of contamination found at a typical gas station with the leaking underground fuel tanks and the commonly forgotten surface spills. During site walks on this site one can see the existing overhead structure (Figure 3.18) and a large portion of the asphalt that has been removed and backfilled with soil and rock (Figure 3.19). These qualities give a clear understanding of where the pump stations and underground storage tanks were located. From this we can infer the locations of contamination by taking into consideration where individuals would spill gasoline, either through transfer from truck to tank or pump to vehicle, as well as, where the underground storage tanks would be leaking. Coupling this information with site specific information like topography, existing vegetation and surface materials helped create a contamination profile.

It was important during this process to take into account the surface and subsurface materials on the site and locate the permeable and impermeable areas. The area of the Getty site that is impervious is predominantly composed of asphalt surface that is accompanied by a typical subgrade base of layers of rock and concrete that is located under the overhead structure. The concrete and its location is typical of gas stations due to its durability when exposed to petroleum products like gasoline. Gasoline exposure to asphalt incites degradation more quickly as it is made of similar compounds and chemicals.

Figure 3.18 shows existing overhead canopy


Figure 3.19 shows the area where the underground fuel storage tanks were located

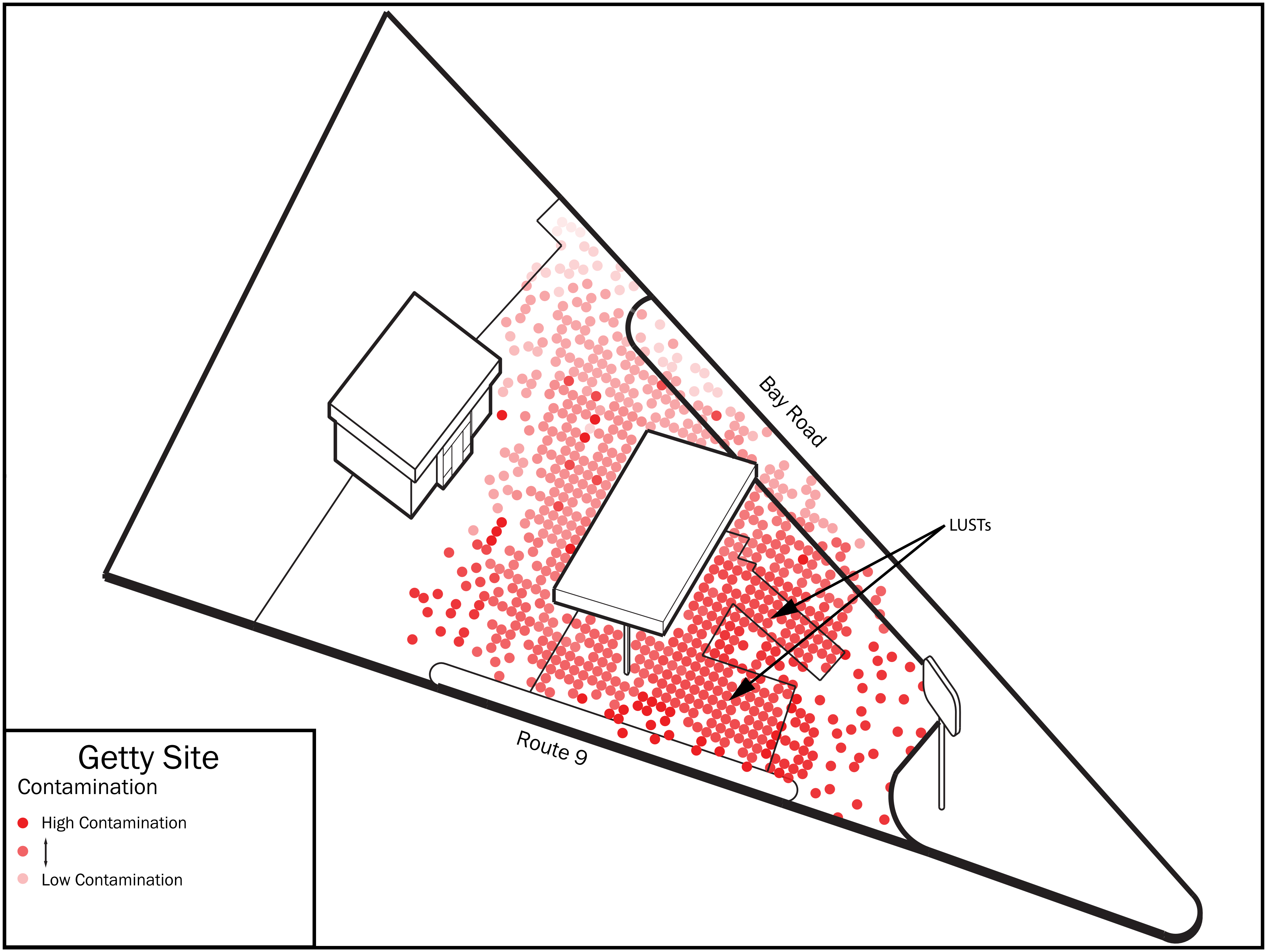



Figure 3.20 Contamination Map of the Getty Site

## Existing Conditions

Through the analysis process a better understanding o f t he site was reached. As it stands the Getty Site represents what is a derelict and abandoned site but is also forming a regenerated landscape. This is evident through the plants that are beginning to grow from the exposed soils. This type of change represents its own level of benefits that can be understood in a way that is beneficial to further progress (Figure 3.21).

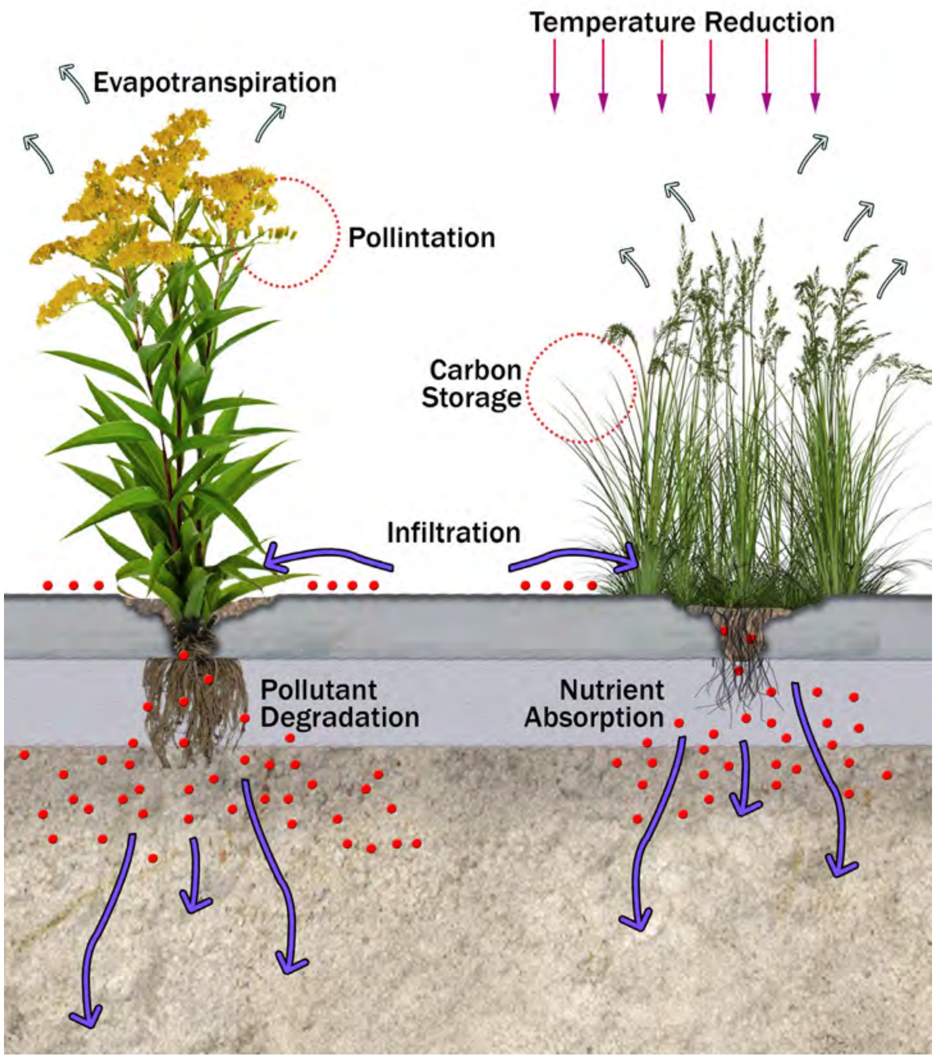



Figure 3.21 Ecosystem services of a regenerated landscape

Further inspection of the site is also needed in order to best apply the appropriate phytotypologies to the site. As mentioned earlier, these typologies can be utilized in a most efficient way by adjusting them according to site specific qualities (Figure 3.22).

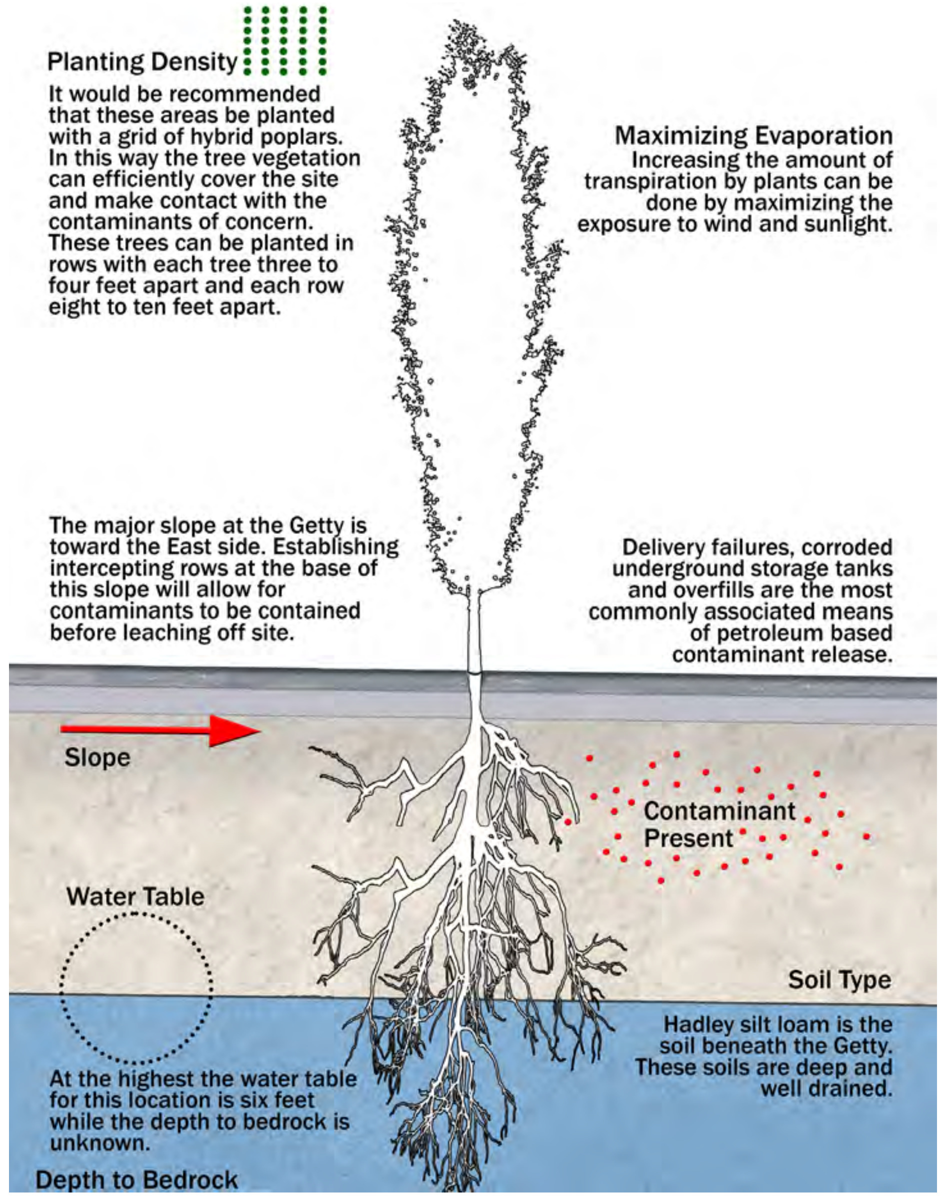



Figure 3.22 shows site specific factors that influence plant selection.

Again, the most important factor to understand is the contaminant present. In the case of the Getty Site we know that the contaminants are lighter fraction petroleum contaminants. These contaminants include gasoline and gasoline additives like MTBE (methyl, tertiary butyl, ether) and BTEX (benzene, toluene, ethyl benzene, xylene) and are by nature organic and capable of being removed through phytoremediation.

The slope of the Getty Site is to the Southeast towards the entrance on Bay Road (Figure 3.23). This direction is also towards the marsh area which is much lower than Bay Road.

As mentioned earlier, the soils are Hadley silt loam and this soils can reach depths of 68 inches below the surface. The depth to water table ranges from 48 to 72 inches while the depth to any restrictive feature is more than 80 inches.

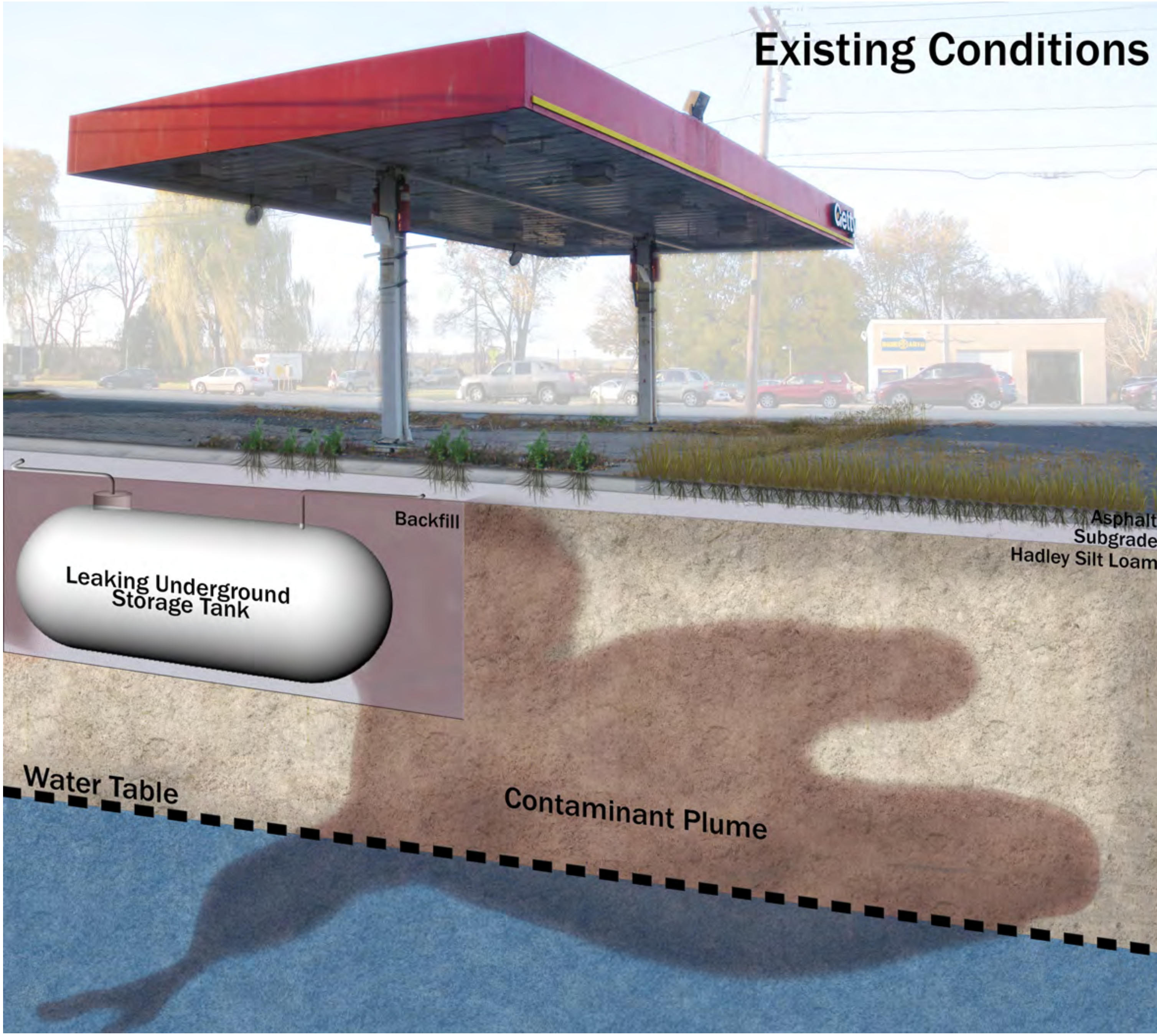
Figure 3.23 shows the sloping of the site as the asphalt is pitched toward the source of photo

Figure 3.24 shows a cross-section of the Getty Site as it exists now. This diagram shows the locations of the leaking underground storage tanks and the contamination plume moving toward the water table. Included is the species of plant material that has come forth during the process of dereliction.

Figure 3.25 is an early concept for the rehabilitation of the Getty Site. This includes plant material chosen to be used on the site, as well as, locations of different phytotypologies. These typologies were chosen based off of information previously discussed. The area directly under the degradation cover is home to pollutants located closer to the surface and therefore more appropriately remediated by  grasses and shrubs.

Directly under the degradation bosque lie pollutants from the LUST that have been matriculating down gradient in the soils which has allowed them to move deeper. To reach these pollutants it was necessary for trees with deeper roots to be established in this location. This is why a degradation bosque was chosen for this area.

This concept provides a basic framework for the redesign of the Getty Site using phytoremediation, but does not yet include any cultural, educational, or thematic elements that can be used to separate phytotechnology from phytoremediation. To help reach that goal, the process for this redesign used the implementation of inspiration from case studies and design concepts.




## Vegetation

*Geranium maculatum*
Wild Geranium

*Solidago* - Goldenrod

*Unknown Brush*

Figure 3.24 shows a cross section of the Getty Site and its existing conditions

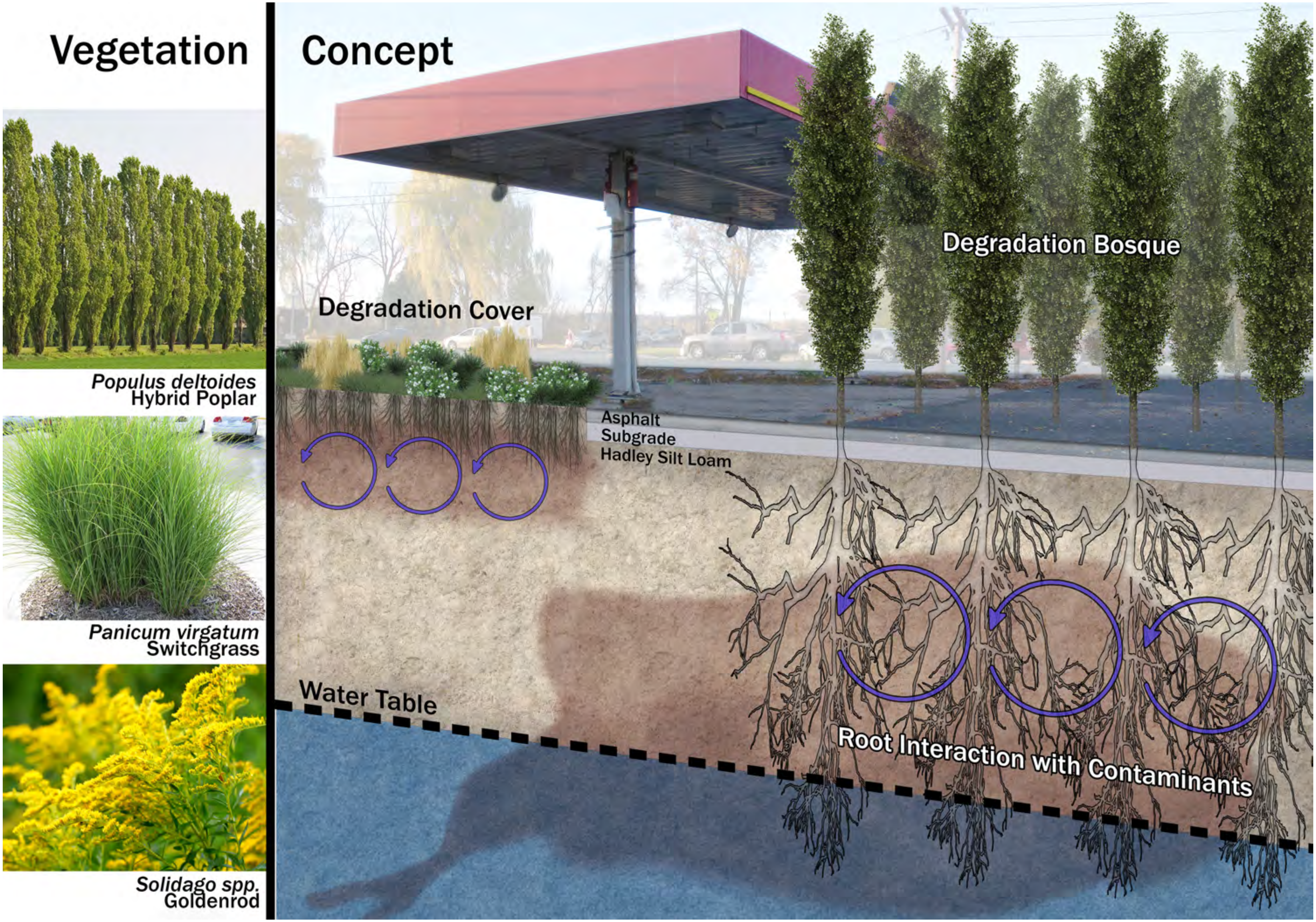



Figure 3.25 shows a conceptual deisgn for the Getty Site utilizing phytotechnologies

# Inspiration and Concept

# Inspiration and Concept

## Case Studies

Deciding which works to include as case studies was primarily a process of researching successful remediation projects that also exuded a sense of beauty. It was not enough to find successful remediation, because it is the thought here that the land deserves to be done right by the process and be given the opportunity to be something more than just clean. Next, it was important to find a variety of projects that touched on individual portions of the Getty Site, instead of finding repetitive projects that seemingly say the same thing. Each of the case studies below shine a light on a specific part of the Getty Site project in a way that is unique and beautiful.

### Gas Works Park

Gas Works Park opened in 1975 on the shoreline of Seattle, Washington, a city that has long been a progenitor of creative and sustainable methods of working with the built environment and how it intersects with the community. This park was grown out of the remains of an industrial relic which served as a gasification plant from 1906 to 1956. Polluted soils, abandoned facilities, and a great location for visitors were all considered in the design process to enable a progressive approach to utilizing the landscape. Leaving aside the beautifully crafted landscape, designed by Richard Haag, this project was an inspiration in several overt ways. First and foremost, the decision by the design team to leave a portion of the industrial relics as a key design feature was something that seemed like an ideal fit for a gas station remediation. These ruins give users a notion of the site's history and speak to how these landscapes are able to change over time if given the opportunity. The towers that once functioned as gas generators, oil absorbers and oil coolers serve as an unusual, but supremely interesting facet of the design that create interest within the boundary of the park, but also from afar. Too often the turnover that pervades the built environment that we inhabit is continuous and relenting without any indication of the past or future, only the present exists in a place unto itself. Memories, events and the fabric of life that was once created is lost to the progression of time and the perceived best interest. One might think that erasing all traces of a bleak history might be a good thing for a site that is deemed inhospitable. This is understandable, but it would regrettably limit a connection with the landscape's story in its truest sense.

The story left behind for those that visit, or even pass by Gas Works Park, is an idea that was incorporated in the design of the remediated Getty Site. If only a small homage to the impact that the landscape endured as a result of the necessities of human transit, the large overhead structure that serves as shelter during fuel pumping was retained at the Getty Site. The inclusion of the overhead structure was especially important for this project as one of the goal was to present a dialogue between the landscape and the user and the past impacts are important in accomplishing this. These structures are ubiquitous in our landscapes and are often seen as unappealing conveniences along miles and miles of American roadways, almost as a beacon of industry on a commercial scale. In that regard an isolated overhead gas station structure atop the Getty Site would immediately tell a story that might have otherwise been swept away with a bulldozer. In this way one can begin to understand the place more thoroughly and begin to piece together clues as to why it might not look like a place they have been before and that perhaps the nuanced abnormalities of the site are indicative of the impacts beheld upon the site prior to introduction. Without the gas station relic indicating this the whole process of remediation might not seem germane.

Gas Work Parks also exemplifies how a remediated landscape can serve as a node along a bike pathway, which inspires the Getty Site's potential to do the same with the Norwottuck Rail Trail. Gas Work Parks connects to the Burke-Gilman Trail, a rail trail opened in 1978 that stretches 19.8 miles along part of Seattle's vast abundance of waterfront. The park came first and became a natural point of beginning, or ending, for the first leg of this trail. Having a destination always makes a trail more meaningful after all. The Getty Site is inspired by this as it's redesign is meant to serve as a point of separation along the Norwottuck Rail Trail. At this location it is hoped that a new infrastructure of bike paths can branch off of the main line of trail and head off in a tangent to better serve the community as a means of transportation and recreation. This is possible because the site redesign allows for visitors and passersby to occupy the space and refresh or reengage themselves in their activity, whether it be through resting, maintenance, or nourishment.

https://www.lonelyplanet.com/usa/seattle/travel-tips-and-articles/cycling-seattles-burke-gilman-trail/40625c8c-8a11-5710-a052-1479d2772957

https://www.seattle.gov/parks/find/parks/gas-works-park

## Landschaftspark Duisburg-Nord

Landschaftspark Duisburg-Nord is one of the great examples of an industrial site being remediated and repurposed for the use of the public. For this reason it was drawn upon for inspiration on how to communicate a site's history and future to those experiencing it.

Located in the Ruhr District of Western Germany, the Landschaftspark was once home to a fully operational steel raw iron factory that operated from 1901 to 1985. The increasing importance of the resources led to the a nearly 500-acre landscape that was impacted by the harsh reality of industrial practice. Upon its closure in the mid-1980's the polluted soils and groundwater in the area deemed the site a wasteland that would need full scale demolition in order to see future purpose.

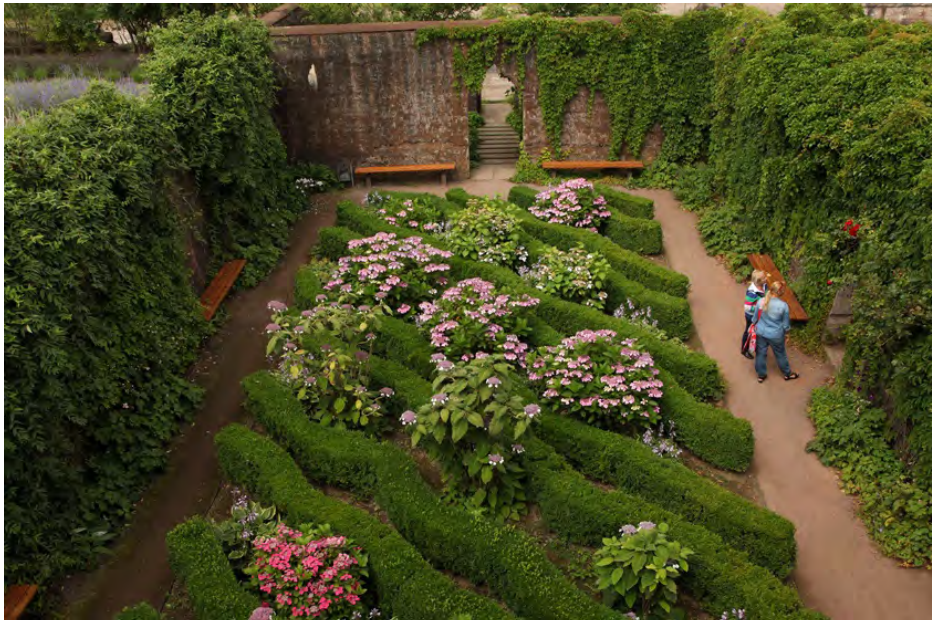
In the early 90's a new approach was proposed that defied the conventional wisdom of soil remediation as Peter Latz and his team introduced the concept of phytoremediation as a way to treat the site. In this way, the polluted soils could remain and undergo a cleaning process carried out by the strategic planting of vegetation. This method followed in the overarching theme of designing for memory, as it also called for many of the original structures to remain and be re-purposed just as Gas Works Park did. Clearly, the work at Landschaftspark provides a direct relationship to the goals and objectives of the redesign of the Getty Site, albeit at a much larger scale.

The main tenets of the design philosophy at Landschaftspark which include; phytoremediation, reclaiming industrial structures and memory relate perfectly to the ideals created for the Getty site. These themes, however, were not the only inspiration attained through looking at Landschaftspark. One of the most interesting design features of Landschaftspark is how the park implements a series of individually operating systems that hold a unique pattern to themselves. These systems appear as the low-lying water park, single fields of vegetation, street level promenades, railway parks and what is called the rail harp. These patterns overlap occasionally at very specific points that promote a visual or functional appeal. The interest and appeal to these concepts derives from inherit need to begin to tell the sites story as the landscape itself informs the pattern and function necessary. Imposing a blank-slate concept on a site effectively removes the history that it is derived from and severs any chance for a continued memory.

What Landschaftspark inspired in the Getty Site is the importance of letting the site inform what should occur and in what locations. This allows for a story to be framed in relation to its history while also alluding to its future through the remediation process. All images courtesy of Latz und Partner and gathered from https://www.latzundpartner.de/en/projekte/postindustrielle-landschaften/landschaftspark-duisburg-nord-de/

Enclosed spaces are given unique characteristics that promote exploration throughout the park system

Designers created a bevy of spaces that conformed to the original structure



Utilizing the existing structure creates interest and a basis for design

These trees combine phytoremediative properties with aesthetic appeals

This park creates a habitat for all levels of life, expanding ecosystem services

## PlantWorks

PlantWorks is a small experimental project located in Hyannis, MA. The project is the work of Kate Kennen's firm Offshots, Inc. Kate Kennen's work has been cited numerous times throughout the Getty Site project, so it was only natural to become familiar with work she has been a part of.

This project in particular provided inspiration because the site was formerly an abandoned gas station and it also succeeded in achieving multiple goals. The main function of the site redesign was to beautify a portion of the main gateway into downtown with plants that would provide bold bands of color for passing traffic. These plants could then be transplanted to public works projects where budgets might not have allowed for additional vegetation. These plants were laid out in easy to maintain rows adjacent to simple paths for maintenance and walking.

The second function of the site redesign was to remediate hydrocarbons and lead that were found in several hotspots in the soil. The specific plants needed for this were implemented where necessary within the overall design scheme of the site which merged function with form in a way that was visually pleasant. The assertion that remediated landscapes can also be visually appealing was an important concept in the Getty Site redesign because it exists in such a high visible location. This led to the Getty Site design having a strong emphasis on merging form with function and vice-versa in a way that leads to a visually pleasing, highly functional design that works within the order and pattern laid out.

Offshoots Inc. 2009

Offshoots Inc. 2009

### Former BP Site Park

Located in Waverton, Australia, this 7 acre park was built upon a former oil processing facility that was owned and operated by BP. What was once a collection of 31 oil storage tanks and other facilities has transformed into a quiet harbor front park that highlights past, present and future aspects of the landscape. One of the main goals for the Getty Site redesign was to portray these differing temporal aspects in the landscape and the BP Site Park was a great case study and inspiration for this.

During the remediation process for the BP Site there was extensive removal of industrial structures that left behind the massive circular concrete platforms that they stood upon. The striking visual of these forms was highlighted in the design and used as a main design feature. In this way the design does not stray from the landscapes past, but offers insight into how it has been developed and repurposed overtime. This relationship between past and present is particularly interesting because it shows how resilient a landscape can be and how it can be changed to serve different purposes. By alluding to the history once present here the design is able to tell a story to the user and provide insight into landscapes beyond the one they are currently experiencing.

McGregor Coxall 2004

McGregor Coxall 2004

McGregor Coxall 2004

# Design Concept

## Hydrocarbons

When searching for inspiration that would h elp address t he form and organizational properties of the Getty Site redesign it was apparent that two ideas seemed to dominate the logical approach for an answer. The first of which was a simple hexagonal shape. During the research phase of the project this form was seen countless times as it is used by chemists to represent the structure of a hydrocarbon (Figure 4.1). As mentioned earlier, a hydrocarbon is a molecule composed of only hydrogen and carbon. These are found naturally in crude oil which has been supplied with an abundance of carbon and hydrogen from decomposed organic matter. T hese m olecules stay intact a s t he substance i s refined into gasoline and gasoline byproducts until they are u sed for f uel and combusted.

Being that the entire reason for this project is in an abstract way due to these hexagonal forms polluting the soil it seemed poetic to use that same form as a means for the site's remediation. The implementation of this form came about in two ways. The first of which in the design of the three social spaces located within the design, which will be discussed more in-depth in later sections. The second is in the arrangement of the second idea that dominated the logical approach for form and function.

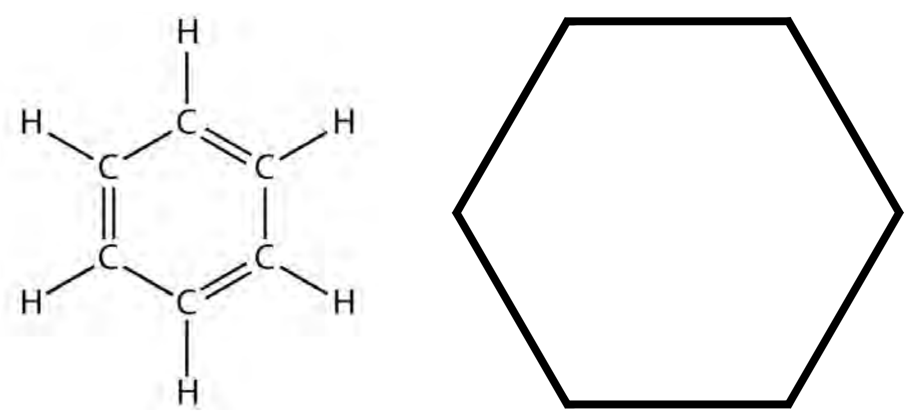


Figure 4.1 shows the hydrocarbon and its relation to a hexagon

## Poplar Rows

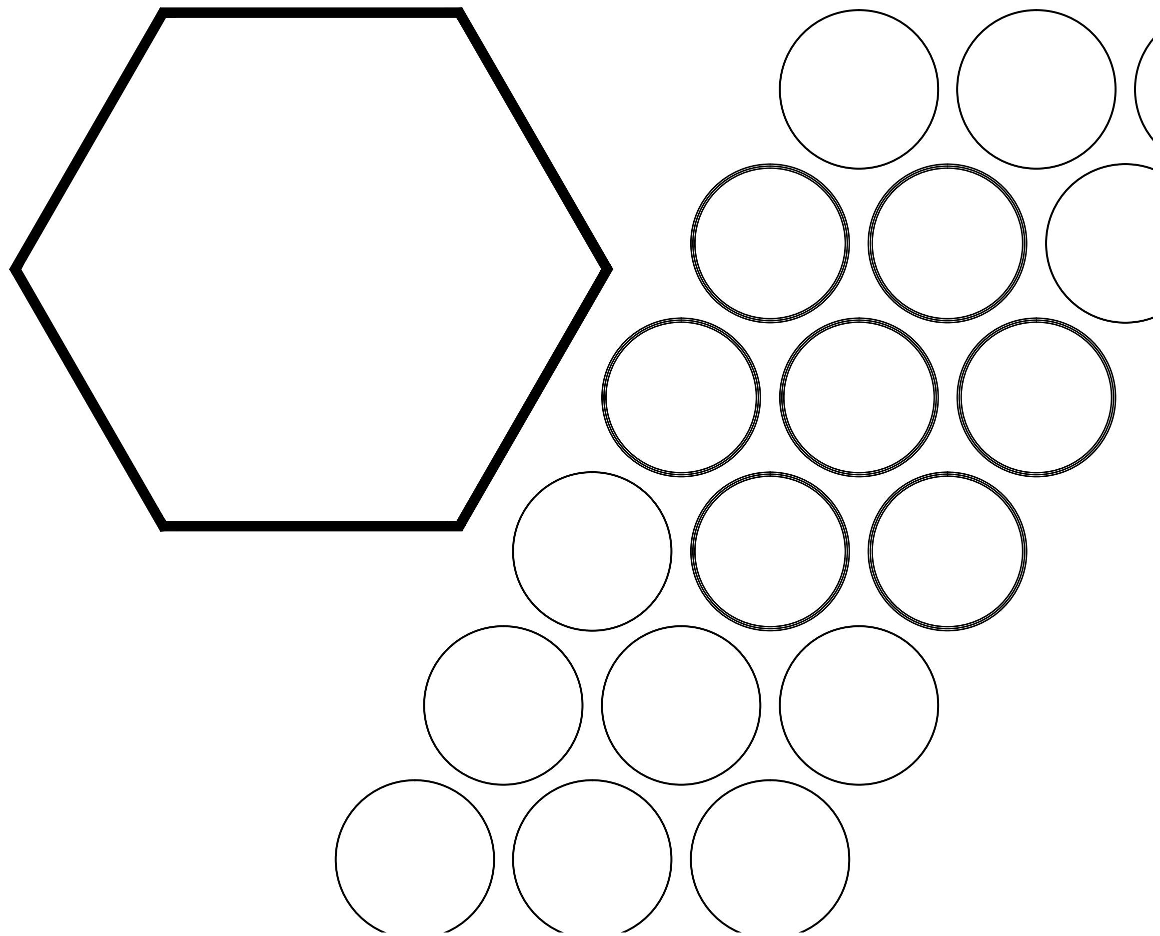
Poplar rows are synonymous with phytoremediation (Figure 4.2). The poster child for this method of site cleanup can be seen in a great many number of articles, books and websites. The reason for this is due to efficiency.

The poplar in all its different varieties is one of the hardest working phytoremediation plants researched thus far. It has been seen to be the most effective type of tree for many different pollution types and scenarios. To maximize its efficiency, these plants, like any, are planted in long rows to act as a blanket or net for the pollutants that might be passing under them in the groundwater or sitting idle in the soil. These grids, as they come to form, ensure the most likely method for success as it leaves no part of the landscape untouched. When designing the Getty Site, these rows became a major design element in the orientation and arrangement of the site.

Figure 4.2 shows a poplar tree row

## Merging the Two Ideas

These two ideas became the basis for the organization of the site and it was the intent to merge the two ideas together by taking poplar tree rows and shifting them slightly to emphasize the hexagonal form. Poplar tree rows normally lie on a four-point grid thus creating squares out of the space between the trunks, like a checkerboard. By shifting their arrangement slightly one can create a five-point grid that begins to emphasize a hexagonal shape. This combination works beautifully and subtly merges two important ideas seen during the design process.



# Design

# Design

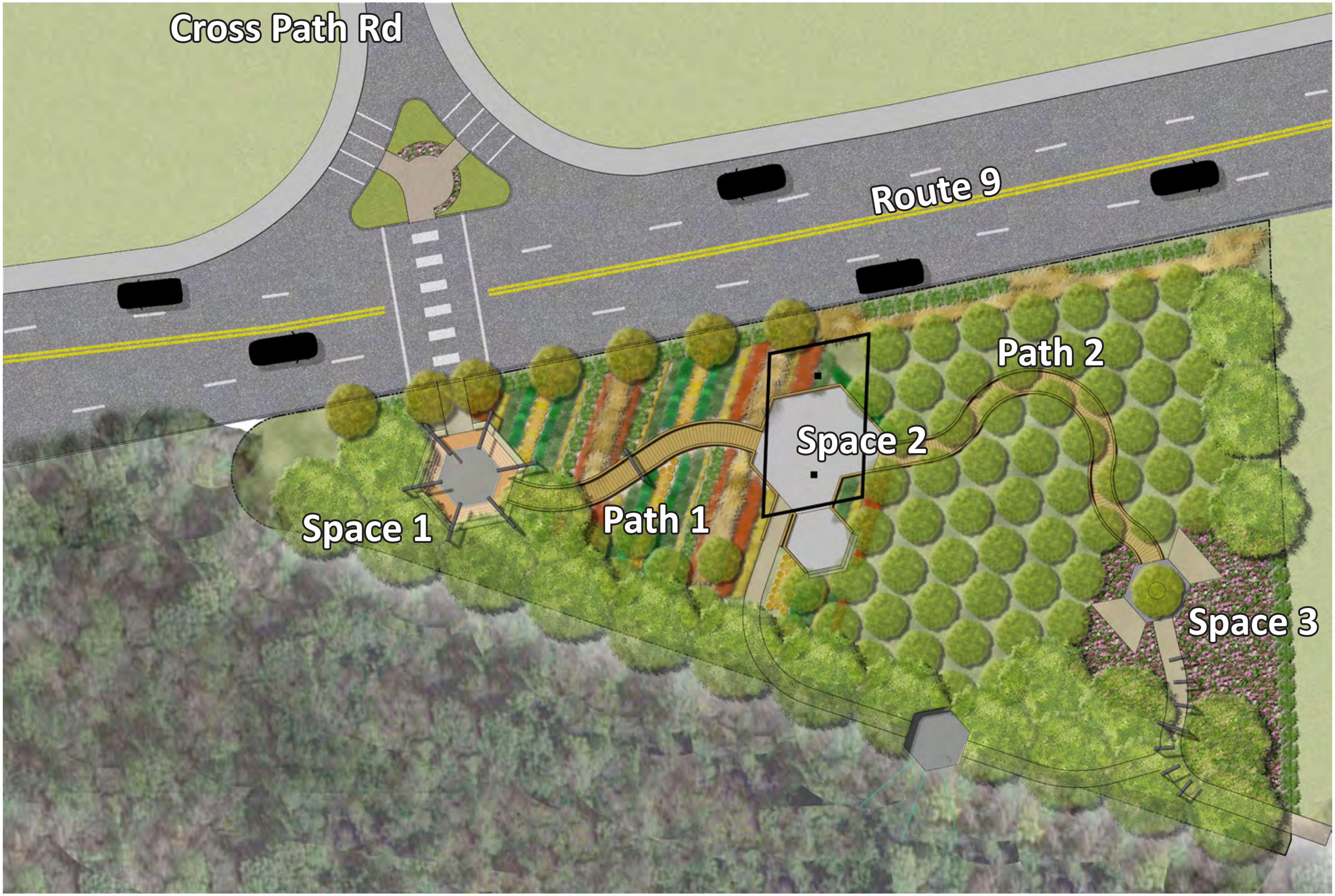
The theme for the design of the Getty Site is a story of progression, from a problem to a solution. To understand this transformation, one is not able to simply be shown the site as a final product. It is more appropriate to experience the mechanisms at work and move through the space on a journey with the site, as the landscape tells its story. This is done by placing the user on a path that leads them through the site where the paths and spaces are representative of the process of phytoremediation. During this representation the site is exposing itself as a contaminated place that is undergoing the remediation process. The story is shown literally through the land, as well as, metaphorically through the form and function of the spaces and movement intended by the user.

The entire site is laid out on a five-point grid system. This provides order for the design and also creates a hexagonal pattern that relates to the overall design concept. The only forms that disrupt this pattern are the pathways, which represent the organic process of decontamination. Accordingly, the process of phytoremediation breaks down the 'hexagonal form' of the hydrocarbon, so too does the pathway break down the hexagonal form of this design.

As a whole, the site is entered from the North side by crossing Route 9 from Cross Path Road. The Norwottuck Rail Trail crosses Cross Path Road approximately 125' from Route 9 which allows individuals to exit the Norwottuck Rail Trail and advance towards the Getty Site. This symbolic gesture of having vehicular traffic interfere with accessing the site speaks heavily to the story being told.

The problem being presented is the prevalence of harmful contamination due to vehicles and the unsafe predicaments they give rise to. Having to traverse this vehicular system to reach the Getty Site as an intended point of destination begins the narrative of vehicles as the problem. As one continues through the site they are taken down a path that symbolically addresses the problems subsequent solutions by physically separating one further and further from the noise and hazard the road presents.

Along this journey the site is divided into three separate spaces and two paths, alternating in sequence. Each space is a stop that describes the contamination remediation process while the paths of movement represent this organic process of breaking down the contaminants. As one progresses through the site the form of these spaces becomes increasingly broken down through design and material choices. This is intended to represent the decontamination process wherein the harmful hydrocarbons, represented by the hexagon, are broken down into simpler and more manageable parts. Simultaneously, the contaminated site is undergoing remediation and this is explained at each space and path to educate the user of what is happening. The remainder of this section highlights each portion of the design and its purpose.


Cross Path Rd
Route 9
Path 2
Space 2
Space 1
Path 1
Space 3

## Crossing from Norwottuck

As mentioned, the Getty Site is located across Route 9 from the Norwottuck Rail Trail. This is the first opportunity after crossing the Connecticut River for trail users to exit the trail and head in a more Southern direction. This makes the Getty Site a great location for a trail head for a new route to take users South towards Mt. Holyoke Range State Park and the Hampshire College area.

Providing a safe connection will be the first priority for access to the site. The volume of traffic that Route 9 is capable of makes it a volatile obstacle for pedestrian and bicyclist use. Implementing crossing lights that can be used by pedestrians and bikers is one measure of safety that can be applied to this crossing. Also, applying striping and other automobile prompts to the asphalt can make automobile drivers aware of the need to watch for crossings at this juncture.

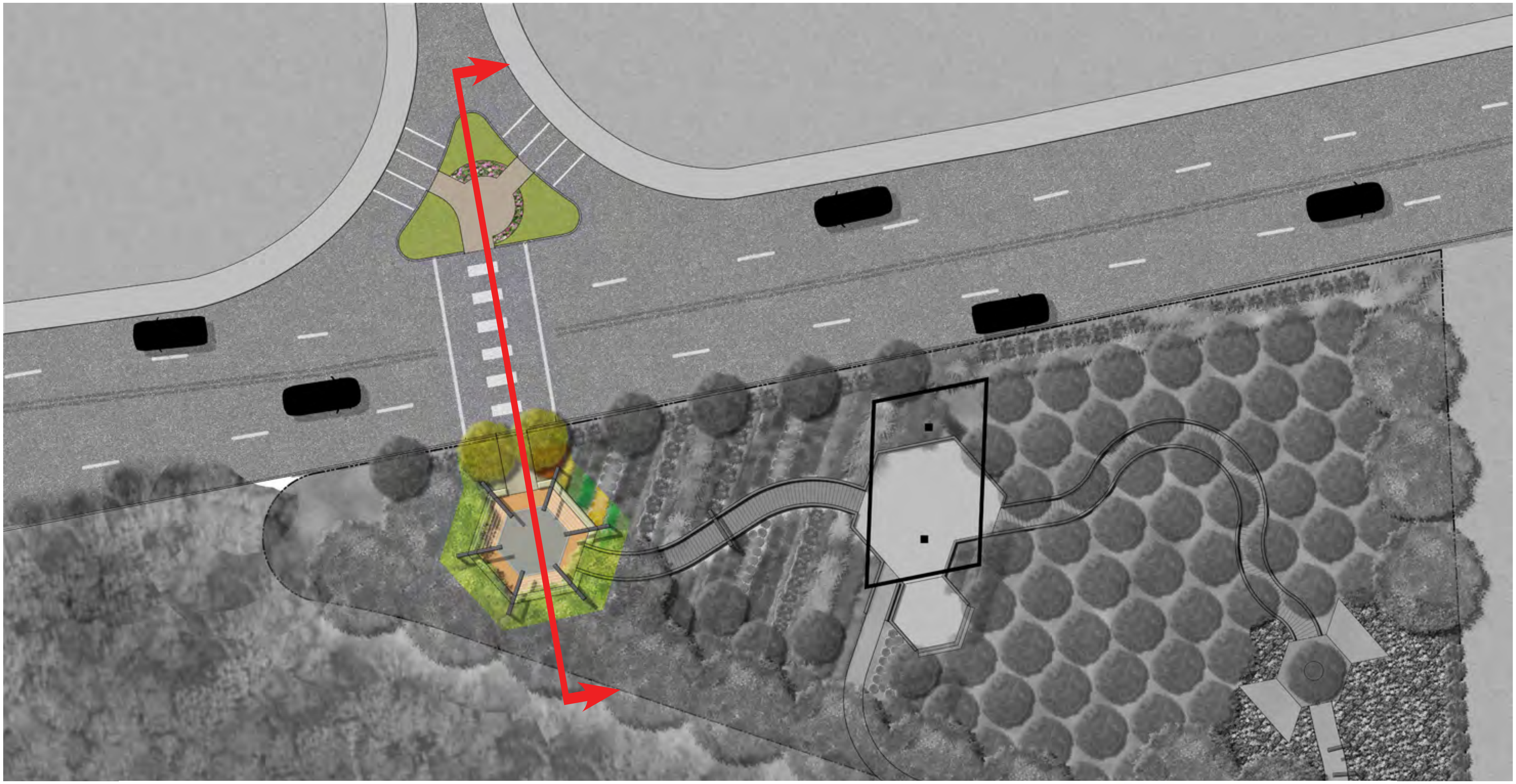
## Space One – Entry

The first space one arrives at after crossing Route 9 is a hexagonally shaped plaza with one entry and exit point. This form is intentional as it symbolizes the characteristic common with hydrocarbons as studied on paper and a strong theme throughout the design. This space and its form is meant to represent the 'problem' being addressed in this project, which is contamination from petroleum based contaminants. The borders of this space are granite seat walls that can be used by users to sit, but also keep them within the space. This space is rigid and intact with little flexibility for use or activity.

Surrounding the hexagonal plaza space are a series of six light features utilized to light the space at night for safety concerns. These are placed offset five feet from the granite seat wall at each corner of the hexagon and further the symbolism of a hydrocarbon as they represent the bond between hydrogen and carbon.

The materials used for the seat walls in the entry space are predominantly granite. Using a very rigid and heavy material like granite for the seat walls represents the strength and rigidness of the hydrocarbon. Granite pavers are also used in the interior of the space to match the seat walls and reinforce the design theme.

The plants surrounding the entry space are plants that wouldn't be classified as capable of phytoremediation. At this location on the site the analysis of contamination deemed it to likely have little to no contamination. This is because it is at the high point of the site and far enough away from contamination sources to not have to worry about exposure to pollutants. Due to this it was unnecessary to include any form of phytotypology. This result also happens to bode well for our design theme. As it is programmed as the problem area it would make sense that no efforts are being made to remediate the area and therefore the plants chosen would reflect that. This allows the design to incorporate plants that might be more aesthetically pleasing than those capable of petroleum degradation and therefore provide a welcome entrance to the site. This shows us that the problem might be aesthetically pleasing on the surface, but it is important to understand what is happening beyond our view. Understanding what is happening below the surface is one of the major educational points that this design is striving to express.




Getty
Crossing Plaza
Route 9
Entry Plaza
Interception Row

## Path One - Surface

As a means of movement through the site and a connection from one space to the next, the first path represents the organic process of phytoremediation. The location of this pathway is above the area of the site that was contaminated with mostly surface level contaminants and is also above the origin of the leaking underground storage tanks. For this reason, this pathway is designated as the surface level pathway. The space surrounding it is mostly open with shrubs on either side of it and your view towards the next space is clear and direct. There is still some relationship to the roadway and the noise it creates, but the user is beginning to distance themselves from that problem now as they head deeper into the site.

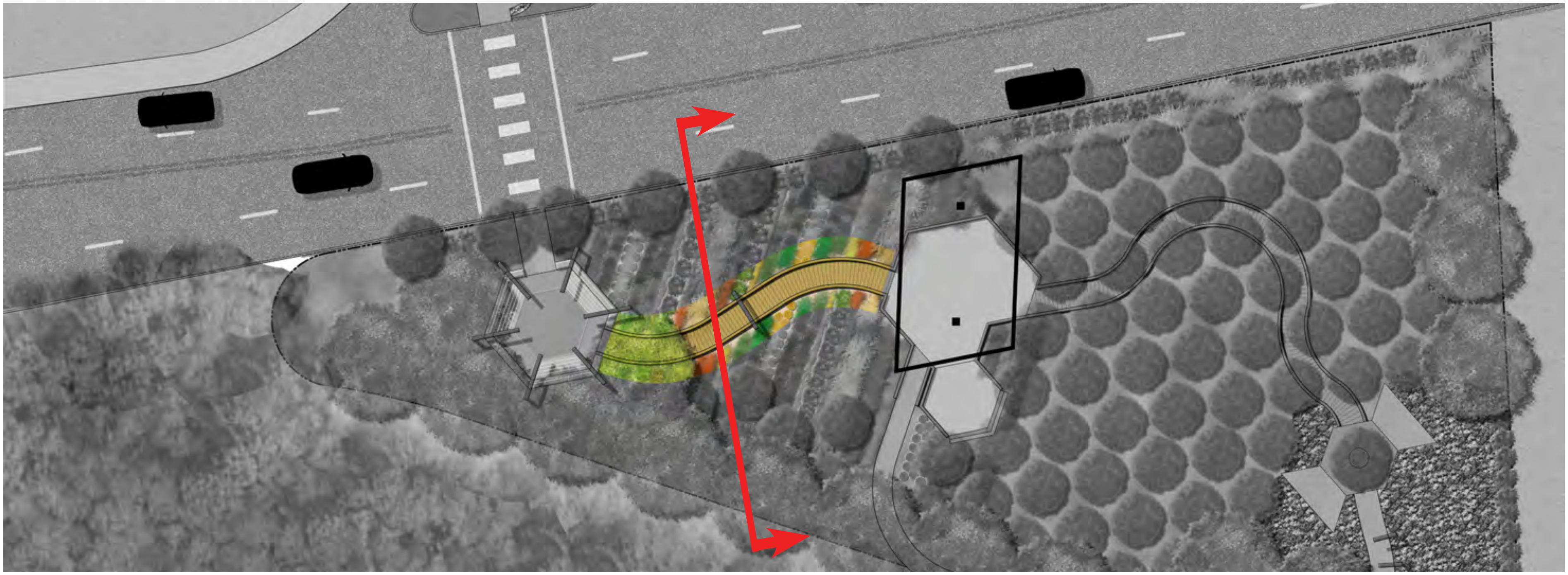
The path is a raised boardwalk that is primarily constructed out of reclaimed timber. The reason for being raised off the ground is to allow water to flow beneath and also provide some separation between the user and the plants and ground. As the environment is theoretically a contaminated site it was deemed necessary to prevent opportunity for entering the planting area. Wire mesh is used in the open spaces of the boardwalk handrails to further detract entering into the planting area. This wire mesh is effective in containing the path while also blending into the landscape and creating a minimalist appearance.

Spanning the boardwalk are hexagonally shaped light fixtures that provide light at night and function as gateways. This helps add a feature of safety while reinforcing the surface (light) feature that will contrast the second path mentioned later.

Instead of a direct straight-line path, there are curves in this pathway. These curves break the grid that the rest of the site is oriented within. This makes a statement about the importance and uniqueness of its form and symbolizes the organic process that the user is undergoing as it follows the site on the path of phytoremediation.

The first path crosses over the first portion of the site that is contaminated per our analysis. As mentioned, this area is stricken with mostly surface level contaminants and requires a treatment to deal with pollutants near the surface. To do this a degradation cover was applied to the location. This treatment uses herbaceous shrubs and grasses that have dense root systems at the surface of the soil that stretch down as far as 3-5 feet below the surface.

The plants chosen for the application of the degradation cover were Agroypyron christatum (crested wheatgrass), Dactylis glomerate (orchardgrass), Elymus hystrix (bottle brush grass), Festuca spp. (fescue), Sagittaria latifolia (broadleaf arrowhead) and Trifolium pratense (red clover). These plants were chosen for their ability to degrade contaminants associated with petroleum products, their root depths and applicability to the climate in Massachusetts. Each plant was arranged in a row of its own at an angle that follows the overarching grid associated with the site. These rows were then repeated in a small plant to large plant fashion. To clarify this planting method, imagine a wave with the trough of the wave being the smallest of the plants and then the crest of the wave being the tallest of these plants with the other falling in where their height dictates. This form is intended to create the illusion of a wave in the landscape, a gesture that is mimicked in the degradation bosque as well. This was done to create interest in the landscape by providing a sense of motion in the planting scheme as the path cuts through these waves and the user experiences the undulating form. Also, the wave form is alluding to the concept of water movement in the upper portion of the soil layers where much of the degradation of contaminants occurs.




Route 9
Air Flow Buffer
Degradation Cover
Boardwalk
Degradation Cover
Multi-Mechanism Buffer

### Space Two – Shelter

Entering the second space welcomes the user to a point where the solution to the problem is presented. Pragmatically, this area provides solutions to the contamination problem through the outdoor educational space attached to the larger space. This area resides at a confluence of phytotypologies, making it a perfect location to have an area where one can be taught and learn about these functioning plants. Here the degradation cover, degradation bosque and stormwater buffer meet.

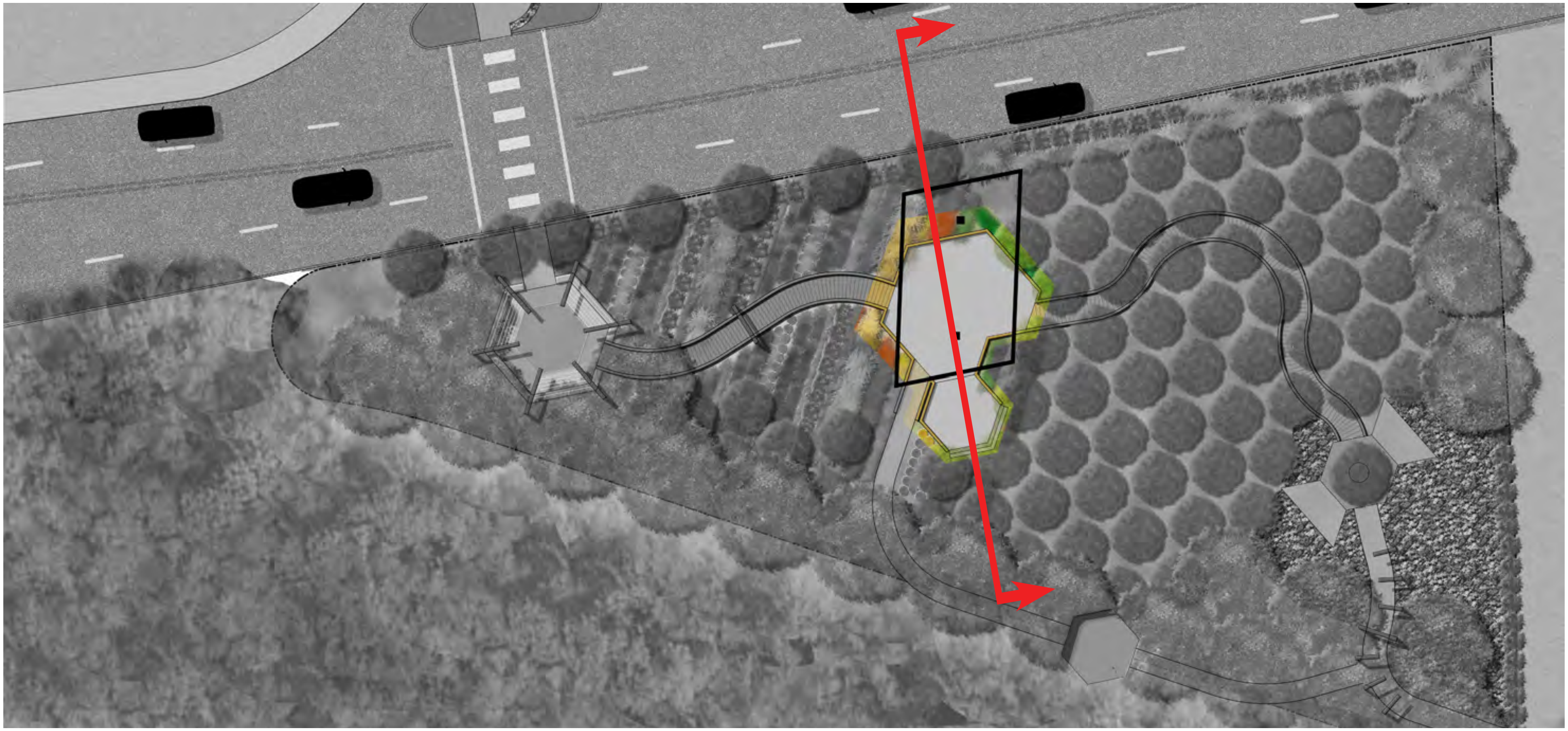
Conceptually, this area provides solutions to the contamination problem by beginning to break down the hexagonal form and moving the user further into the site and further from the entrance and road. It is here, sheltered under the ubiquitous symbol of gas stations that solutions can be taught and awareness can be spread. Leaving the overhead structure in place provides many benefits to the user as it shields from sun and rain. However, it also symbolizes what the site once was, for what is a lesson to be learned without the knowledge and reminder of how the problem came to be.

Realistically, this space also provides practical solutions to those traveling along the trail. This is the main area on the site and can be used as a reprieve from the fatigue or hardships experienced through travel. Water, space to rest, shelter, trail information and repair stations are found here to be used by those in need of such things. This amenity provides a need along the Norwottuck Trail, especially on the east side of the Connecticut River. Being at a place where the trail may split and head in another direction is an ideal location for what could become a major trailhead in the area.

Unlike the rigid materials used in the first space, this area becomes more flexible. The fence edging around the perimeter of the space is the same wood framing and wire meshing used along path one. This provides consistency between the two and shows progression in the process while still providing a buffer and barrier between the user and the plant material. Seating in this area is also more flexible. Wooden benches are attached to parts of the perimeter fencing, but there are also pieces of furniture that can be moved and oriented at the user's discretion. This ability to move site furnishings contrasts the rigidity of space one's fixed stone seating. The surface is smooth finished concrete which also contrasts space one's coarse stone pavers and exposed aggregate.

As the user is lead through the site and break down is represented in multiple ways, the second space follows this theme. Where the first space was a perfect hexagon, the second space becomes deconstructed. A large portion of the hexagon is removed and a smaller secondary hexagon is added. These gestures symbolize a form that is being broken down through additive and subtractive design changes.

Space two serves as a confluence of many different phytotypologies. As a space for learning and problem solving it was paramount to orient as many of these as possible in this location and have them converge around the learning subspace. Here the interception hedgerow, degradation bosque and degradation cover meet. This provides educational opportunity as students can be taught about phytoremediation in many ways. Whether it be plant identification, how these plants work in this environment or how they are monitored for efficiency, having them all in one area makes it a functional place for education.




Route 9
Air Flow Buffer
Main Plaza
Education Area
Multi-Mechanism Buffer

## Path Two – Enclosed

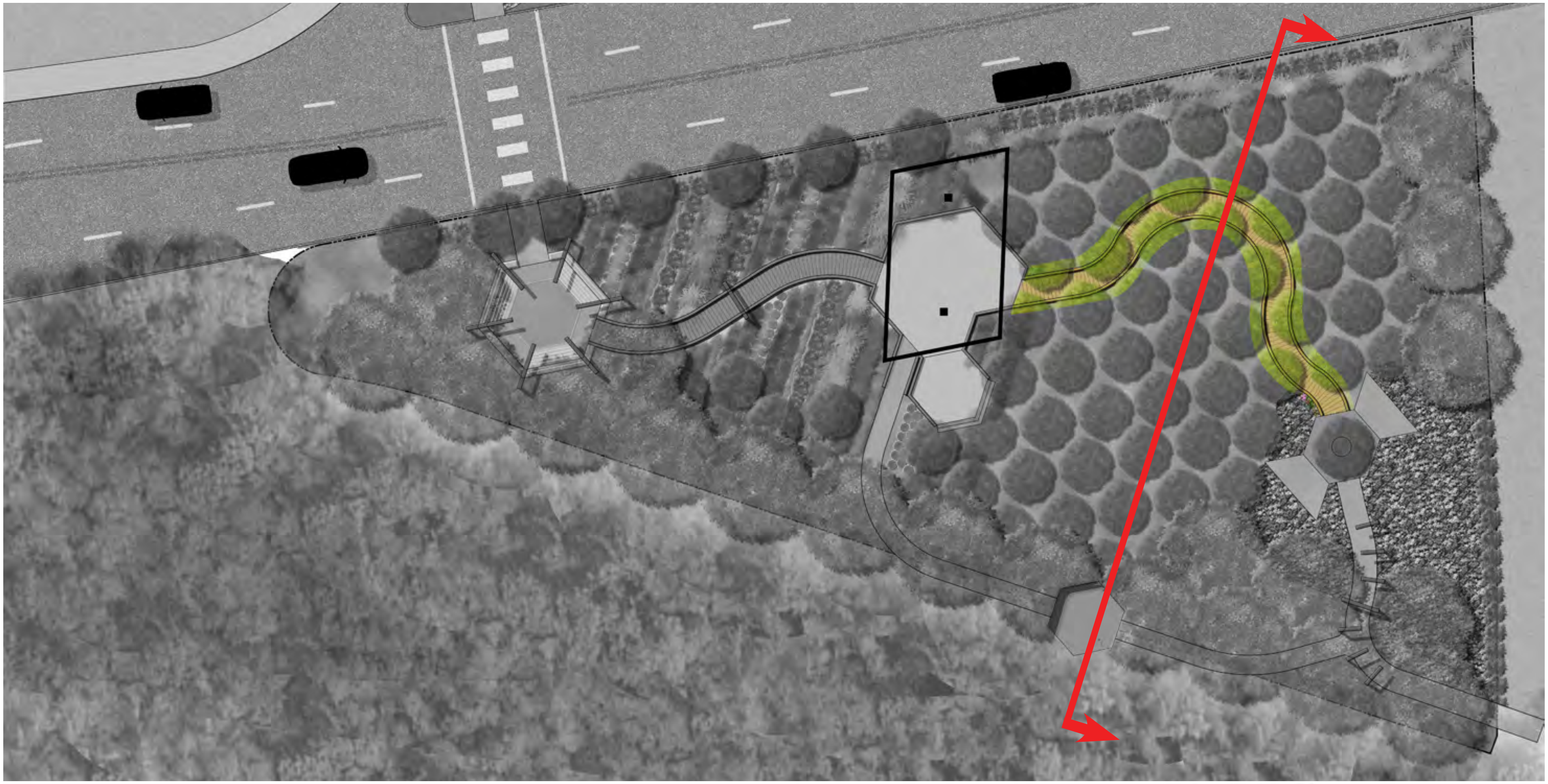
As one moves from the second space they begin on the second path. This path meanders through a bosque of trees which represents the deeper level cleaning done during phytoremediation. At this point of the site most of the pollutants would have begun to travel downwards in the soil as they perhaps enter the water table and migrate down grade. This is why the trees are planted here. Their root systems reach much further down into the soil than the surface level plants that populate the area along the first path. Whereas that path was open and allowed for views at all angle, this path screens its destination and creates opportunity for surprise and wonder. The curvature of this path is also much more pronounced and dramatic compared to the first. As this section is meant to represent the sub-surface level of pollutants, it is designed to feel more enclosed, especially compared to the first path. This is why there is minimal lighting on this path when compared to the first path. Lighting exists within the railing system, but it is much less pronounced and angled downward to minimize its effect.

Like the first path, the second is also a boardwalk. This raised platform rests atop an undulating series of crests and troughs created from earthwork. Dubbed the 'wave field' and drawing inspiration from a similar design of the same name by Maya Lin, this features works functionally and symbolically. As mentioned, this area of the site is concerned with the water table and the dangers of pollutants making contact with it. This wave field represents this, by channeling water from roadway runoff and other parts of the site into the troughs of the waves. In these troughs the grid of trees is planted which allows for a slight advantage in their root systems ability to accept water. These channels run from the northeast to the southwest which directs water away from the low points on the site.

The second path is designed and built in the same manner as the first path. This is done to provide cohesion between the parts of the design that are intended to facilitate primary movement. The only difference between the first path and second path is the intermediate post supports for the wooden handrails are spaced further apart along the second path. This decision helps reiterate the continuing theme of becoming less stable and more open as one moves through the space. The curvilinear nature of path two is more distinct and abrupt than path one. This is partly due to the need to move through the bosque of trees that it is planted in, as well as, there being a larger space to work with. A variety of views are created as ones orientation shifts while moving along path two.

The primary phytotypology that path two interacts with is the degradation bosque. This bosque is placed on the same five-point grid system that the entire site is placed on, which helps strengthen and highlight the hexagonal theme throughout. This typology was placed in this location because it is on this portion of the site where the pollutants would be at a lower level. As the leak from the underground storage tank moves downhill through the soil it was necessary to install a plant species and typology that could reach as deep as possible to intercept this flow. The large grid of trees creates a root system barrier that will work to pump groundwater towards these trees and prevent any off-site flow.

The species chosen for the degradation bosque is are hybrid poplar trees (Populus trichocarpa x deltoides) Populus spp. This tree has been proven successful in many case studies that target hydrocarbons (Kennen and Kirkwood 2015, p 92). The columnar growth habit allows for a dense and legible planting design and its deep and fibrous root system creates a large surface area for contacting pollutants. Being that it is the most popular tree for phytoremediation it seemed appropriate to have it highlight this particular design.



Route 9
Buffer
Degradation Bosque
Boardwalk
Degradation Bosque
Viewing Area
Existing Edge
Marsh Wetland

### Space Three – Open Space – Deconstructed Form

Our analysis of the contaminants in this area of the site show that pollution levels are minimal and further phytoremediation is unnecessary. This presents an opportunity to create a space unlike any other on the site. As the boardwalk for the second path ends the density of the tree bosque gives way to an open space that exhibits this uniqueness from the rest of the site. This space is open and clear with picnic tables and unrestrained space for gathering. The edges of the space are planted with soft plant material that function primarily for aesthetic and pollination purposes, instead of phytoremediation. This represents the payoff of cleansing the site as it is now capable of producing supporting ecosystem services that drive sustainability while also providing the ability for an individual to enjoy a meal and bask in the beauty of a clean space without hard boundaries. The user is at a point in the site that is as far from Route 9 as possible and adjacent to the new trail extension that leads to the Southeast. The problem of the car is dissolved after undergoing a transformative process that was symbolized by the form and function of the journey.

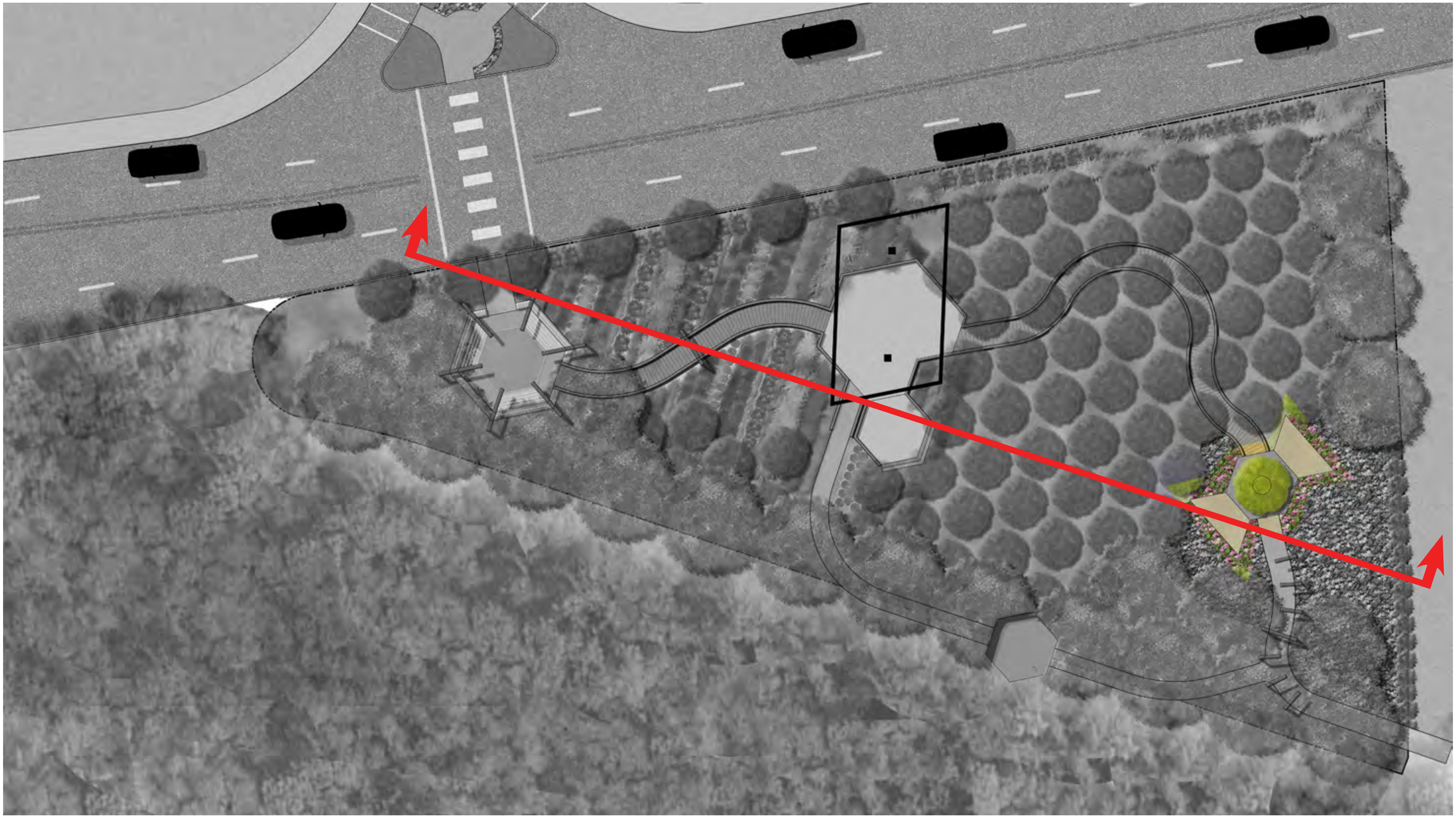
The process of phytoremediation is complete as the hexagonal form is now completely broken down creating an environment that is free of contamination. This is shown in the third space by deconstructing the hexagon into two halves that are mirrored about the path from one another. These spaces are then used as a place for a picnic table that can be utilized by those visiting the site.

Along the path, leading to the trail extension, there are overhead lighting features that resemble those from the first path. Unlike those along the first path, these do not span the path and form the hexagonal shape. They are halved and staggered further reinforcing the deconstruction of the shape in this final space.

The two halves of the hexagon that represent the dissolution of the hydrocarbon are further reinforced with this theme by being constructed out of a decomposed granite surface. This light and attractive material is a breakdown of a much stronger and rigid material and helps symbolize the transition from the first space where granite was the material of choice.

Unlike the rest of the site, this location moves away from using plants that serve the purpose of phytoremediation. On a conceptual and aesthetic level, the plants in this area were chosen due to their flowering properties and colorful displays. This aesthetic is something that is minimal in plants used for phytoremediation. This is intended to represent the clean and final product of the remediation process. As mentioned, pollinator plants were the primary choice when selecting the palette for this space. Utilizing pollinator plants helps reinforce the idea of an environment that is clean and providing beneficial ecosystem services.

Plants included in the pollinator palette predominantly include perennials. These perennials are planted in a mix that creates a rich biodiversity of pollinator-friendly plants that attract bees, birds and butterflies. Included in this mix is salvia, phlox, black-eyed susan, aster, lobelia, milkweed, coneflower, goldenrod and coroepsis. These plants are accompanied by a mix of shrubs along the edges of the space that frame and delineate the space. These are chosen to provide structure while also continuing the theme of providing pollinator benefits. These include butterfly bush, summersweet clethra, bayberry and arrowwood.




Getty
Route 9
Degradation Cover
Boardwalk
Degradation Cover
Education Area
Degradation Bosque and Wavefield
Pollinator Garden

# Conclusion

Phytotechnology as a means for remediating small sites polluted with organic chemicals is a step in promoting this technology and proving its worth for other, larger and more complicated brownfield. While this study explores one possibility of redesigning an abandoned gas station on a highway corridor in Hadley, Massachusetts (USA) it is necessary to expand design possibilities on other abandoned gas stations with different contexts and conditions. The results should also be extended to gas stations in operation to apply phytotechnologies as a preventive method. This design study is relevant for the profession of landscape architecture because it merges design aesthetics with science-related technologies. There are still aspects that have been overlooked or need more exploration: process-oriented strategies especially public participation. Implementing and promoting this type of remediation will require community support and involvement, of which can be directed and associated with an experiential transformation of such abandoned and contaminated sites. These findings may be accompanied within a regional process of identifying and networking potential sites while considering them within an established city greenspace or greenway plan.

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