Abid A. Ansari · Sarvajeet Singh Gill
Ritu Gill · Guy R. Lanza · Lee Newman
Editors

Phytoremediation

Management of Environmental Contaminants, Volume 6

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Preface

> Ecological restoration to predisturbance condition, or an approximation thereof, is possible.
>
> John Cairns, Jr.

Volume VI of the series *Phytoremediation: Management of Environmental Contaminants* provides a global selection of research results from 15 countries on several continents. Laboratory and field studies including case histories of applications to contaminated sites describe an array of basic phytoremediation approaches, mechanisms, and potential applications to clean up and monitor aquatic and terrestrial ecosystems. Chapters include the landscape redesign of abandoned gas stations using practical phytotechnologies, the interaction of plants and microbes to remove different contaminants, new information on soil sorption-release mechanisms as they affect phytoremediation efficiency, and plant surveys of metal/metalloid uptake and tolerance at contaminated sites including landfills and agricultural areas. The use of constructed wetlands to treat water contaminated with fuel and oil hydrocarbons and the removal of metals from industrial and municipal wastewater are covered in several chapters. One chapter describes the PGPR activity associated with the use of wastewater contaminated with metals to irrigate crops. Another chapter details the potential of using lichens in the detection and treatment of cancers associated with toxic metal contaminants. Two chapters report the use of trees and other woody species to clean up contaminated sites, while seven chapters describe the study of both engineered nanoparticles and basic nano-phytoremediation approaches to treat environmental contamination including metals, pharmaceutical residuals, and pesticides.

The development and use of phytotechnologies continues to move forward at a steady pace. More ecologists, engineers, and government officials now recognize the potential of phytoremediation to provide a green, cost-effective, and viable application to address some of the world's many environmental challenges. The editors of *Phytoremediation: Management of Environmental Contaminants* Volumes I–VI have provided important studies of the basic approaches of phytoremediation in a diverse global context. The development and acceptance of genetic editing such as CRISPR and other dynamic new approaches to modify plant/microbe biochemistry and growth bode well for the future of phytoremediation and other phytotechnologies. It is our hope as editors that much of the basic information provided by this series of books can serve as the foundation for the development of new applications that feature the integration of modern research discoveries into new methods to remediate contaminated ecosystems.

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Part I
Phytoremediation Applications: An Update

Chapter 1
Redesigning Abandoned Gas Stations Through Phytotechnologies

Frank Sleegers and Matthew Hisle

1.1 Scope and Introduction

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 [1]. One commonly occurring brownfield site with a history of perpetuating contaminated land is the gas station. Gas stations proliferated throughout the United States in the twentieth 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 [2]. Phytotechnologies have the potential to fulfill the growing need for an innovative, sustainable, low-cost method to address the contamination issues prevalent in soils and groundwater. Upon full remediation, a gas station can offer recreation as public green space or ecological functions that benefits society. "Phytotechnology is about using specifically selected plants, installation techniques, and creative design approaches to rethink the landscapes of the post-industrial age" ([3], p. xxv). This definition 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 [4, 5]. Phytotechnology utilizes vegetation to remediate, contain, or prevent contaminants in soils, sediments, and groundwater and/or add nutrients, porosity, and organic matter.

The objective of this design research project is to showcase new design models and strategies for abandoned, existing, and planned gas stations through

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Fig. 1.1 Aerial photograph of the larger project area. The former gas station is located close to wooded marshlands that connect to the Connecticut River in Hadley, MA (USA) [6]

phytotechnologies as a tool for aesthetic experience, ecological performance, and social resilience in the context of brownfield remediation and adaptive reuse. The project uses an abandoned gas station located on Massachusetts Route 9 outside of Amherst, MA, as an exemplary and typical study area (Fig. 1.1). The outcomes of this project were developed from a Master's Project by Matthew Hisle in the discipline of landscape architecture [7].

1.2 Method

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. *Phyto*, a book by landscape architects Kennen and Kirkwood [4], described the subject with a more approachable set of planning, engineering, and design tools. They developed a toolset of 18 phytotypologies and recommended 9 of these typologies for the remediation of gas stations. This design research project studied all typologies in more detail and selected seven phytotypologies considering the specific conditions of the case study and explored them with other design strategies common to landscape architecture. 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.

1.3 Background

1.3.1 Benefits of Reclaiming Urban Brownfields into Public Open Space

There is considerable literature supporting the benefits of turning urban brownfields into public green space [8–14]. This research purports a variety of different reasons for these benefits ranging from visual preference [11], urban biodiversity [8], increasing property values [10], and positive community surveys [9]. There is unquestionable doubt that brownfields possess the intrinsic potential for becoming environmental or community green space that can clearly stimulate a city's built environment while at the same time remediate contaminants and transform socially and environmentally neglected urban areas [9]. With that said a significant minority, comprising 3–4%, of brownfield redevelopment projects are intended for these uses [9]. One of the major reasons for this is the enormous cost associated with many brownfield remediation projects. Revitalization powered by the promise of housing opportunities and economic gains through jobs, tax revenues, and increased revenues because of residential and commercial redevelopment often overshadows the invisible, qualitative, and long-term benefits associated with green space development [14]. To influence further prosperity in returning urban brownfields to green spaces, the difficulties associated with that transition must be addressed specifically cost and expectation.

1.3.2 Abandoned Gas Stations and Their Contaminants

Abandoned gas stations are establishments that proliferated throughout the United States in the twentieth 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 [2]. The major problem at these locations is instances of fuel leaking underground storage tanks (LUSTs). From 1984 to 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 [4].

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, leaking underground storage tanks, and botched fuel deliveries. The substances contain hundreds of hydrocarbon compounds that create unfavorable outcomes when they come in contact with people, animals, or the surrounding landscape. Typical for gas stations are petroleum hydrocarbon compounds that are considered lighter fractions, meaning they have characteristics that allow them to be more easily broken down. These are gasoline and gasoline additives like MTBE (methyl, tertiary butyl, ether) and BTEX (benzene, toluene, ethyl benzene, xylene), as well as diesel fuel. They often have chemical makeups with single molecule chains which are more water-soluble and therefore more easily degradable. Another group of contaminants typical for gas stations are chlorinated solvents. They occur in thinners and degreasers used during repairs and maintenance on cars. All lighter fractions of petroleum hydrocarbons and the group of chlorinated solvents can be targeted through phytotechnologies. In an ideal scenario, it is possible that organic pollutants are broken down to the point where they are degraded and eliminated as a harmful substance from the soil or groundwater.

Gas stations do incur inorganic pollution, especially if they were built prior to 1970. While this project does not deal directly with inorganic contamination, it is applying prophylactic measures. Inorganics are elements that cannot be broken down or degraded as they are at their most basic state. 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 holds them until the plant can be harvested and transported elsewhere for disposal. The field application of phytoextraction is challenging as it depends on many factors like bioavailability of heavy metals, soil properties, speciation of the heavy metals, as well as the plant's ability to absorb and accumulate metals in its aboveground parts [15, 16]. Phytostabilization, though, has been proven to be a successfully applied technique within the field of phytoremediation ([17], pp. 142–145). It prevents inorganics from moving into vital water sources or areas by holding these pollutants in place with the assistance of vegetation.

1.3.3 Phytotypologies as Phytotechnology Planting Types

Phytotypologies or phytotechnology planting types are a way to organize approaches to remediation in a spatial way to meet design goals while considering the functional requirements. Kennen and Kirkwood [4] created a toolbox of 18 phytotypologies. Each one serves a specific role in the landscape depending on (a) the primary mechanisms such as phytodegradation and rhizodegradation, phytovolatilization, phytometabolism, phytoextraction, phytohydraulics, and phytostabilization; (b) the location of the contaminant such as soil, groundwater, wastewater, and air; and (c) 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 integrate aesthetical and ecoservice functions that are relevant to landscape architecture. In this way a site with a complex pattern of contamination can be treated with a variety of methods to better incite remediation while responding to other, site-relevant issues.

1.3.4 Application of Phytotypologies for Gas Stations and Auto-Repair Shops

Kennen and Kirkwood have described 16 land use categories typical for contamination and crafted scenarios of possible combinations of phytotypologies for their application. Gas stations are one of these categories ([4], pp. 266–267). They suggest nine phytotypologies to remediate gas stations: planted stabilization mat, phytoirrigation, green and blue roof, interception hedgerow, degradation bosque, degradation hedge/living fence, degradation cover, airflow buffer, and stormwater filter (Table 1.1). All plants should be petroleum-tolerant species (Table 1.2).

1.3.4.1 Planted Stabilization Mat

A thickly *planted stabilization mat* holds pollutants on-site and prevents migration to minimize human and environmental contact. Metal excluder plant species prevent mobility of pollutants into aboveground plant tissues and therefore minimize wind and soil erosion. The plants have to tolerate the specific level of contamination.

1.3.4.2 Phytoirrigation

Phytoirrigation retrieves polluted groundwater from subsurface contamination plumes and pumps it to the surface to be reused for irrigation. This typology should 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 come in contact with the plantings' root zones [4]. The selected plants must be quick-growing and petroleum-tolerant species with a high evapotranspiration rate to absorb and process water quickly and efficiently. This is applicable to up to 30 ft deep-rooting phreatophytes.

Table 1.1 Description and overview of 18 phytotypologies, their mechanism, target contaminants and media, general criteria for plant selection and function

Phytotypology [a]	**Phytotechnology**	**Contaminant targeted** [b]	**Contaminant subject**	**Plants suitable**	**Function and description**
1.Planted stabilization mat	Rhizofiltration Phytostabilization	Metals[c] POP's Salts in soils	Soil 0-18 in. be- low surface	Metal excluders Contaminant-tolerant plants.	Holds contaminants on site.
2.Evapotranspiration cover	Phytostabilization Phytohydraulics	All types of contami- nants	Stormwater	Plants with deep tap roots and high evapotranspiration rates – phreatophytes.	Minimizes water infiltration and prevents contaminant mobilization.
3.Phytoirrigation	Phytodegradation Rhizodegradation Phytovolatilization	**Petroleum** **Chlorinated Sol- vents** Nitrogen Selenium Tritium	Wastewater or groundwater	Petroleum tolerant/ chlorinated solvent tolerant. Plants grow fast with high evapo- transpiration.	Irrigating plants with contaminated water.
4.Green and blue roof	Phytohydraulics	All types of contami- nants	Stormwater	Draught-tolerant species.	Minimize stormwater runoff.
5.Groundwater migration tree stand	Phytohydraulics	**Petroleum** **Chlorinated Sol- vents** Nitrogen Radionuclides POP's Metals	Groundwater 0-20 ft below surface	Trees with deep tap roots and high evapotranspiration rates – phreatophytes.	Trees pump and treat groundwater.
6.Interception hedgerow	Phytodegradation Rhizodegradation Phytovolatilization Phytohydraulics Phytometabolism	**Petroleum** **Chlorinated Sol- vents** Pesticides Nitrogen	Groundwater 0-20 ft below surface	Trees with deep tap roots and high evapotranspiration rates – phreatophytes.	Roots tap into groundwater and keep fractions of contam- inants from migrating.
7.Degradation bosque	Phytodegradation Rhizodegradation Phytovolatilization Phytometabolism	**Petroleum** **Chlorinated Sol- vents** Pesticides Nitrogen	Soils (0-10 ft)	Petroleum tolerant/chlorinated solvent tolerant. Plants grow fast with high evaptranspiration.	Deep rooted trees and shrubs degrade contamination within the soil profile.

8.Degradation hedge/living fence	Phytodegradation Rhizodegradation Phytovolatilization Phytometabolism	**Petroleum** **Chlorinated Sol-vents** Pesticides Nitrogen	Surface Soils (0-4 ft)	Petroleum tolerant/chlorinated solvent tolerant. Plants grow fast with high evapotranspiration.	Shrub species degrade contamination.
9.Degradation cover	Phytodegradation Rhizodegradation Phytovolatilization Phytometabolism	**Petroleum** Nitrogen	Soil (0-5 ft)	Deep rooted drought tolerant prairie grass species. Mixed species.	Deep-rooted herbaceous species remove contaminants.
10.Extraction plots	Phytoextraction Phytometabolism	Arsenic Selenium Nickel Long-term: Cadmium Zinc	Soil (0-3 ft)	Limitations through climate, toxicity and bioavailability.	Hyperaccumulator plants or high-biomass crop species extract inorganic pollutants or organic pollutants Harvesting necessary.
11.Multi-mechanism mat	Phytoextraction Phytometabolism Phytodegradation Phytostabilization Phytovolatilization	All types of contami-nants	Soil (0-5 ft)	Selection based on contaminants, overall soil conditions and overall targets for the area.	Combination of phytotypologies as mixed herbaceous planting using a broad range of phytotechnology mecha-nisms while providing other ecosystem services.
12.Air flow buffer	Phytoaccumulation	Air pollution particu-late matter	Air	Species with a high rate of ac-cumulating particulate matter.	Interception of particulate matter from moving air through leaf surfaces of vegetation.
13.Green wall	Rhizodegradation Phytosequestration Phytometabolism Rhizofiltration	VOC's Air pollution particu-late matter	Air and/or water	Diversity of species to intercept particulate matter and cleanse it in the root system of the plant.	Installations of plants on vertical surfaces with or without soils.
14.Multi-mechanism buffer	Phytostabilization Phytohydraulics Rhizodegradation Phytodegradation Phytovolatilization Phytometabolism	All types of contami-nants	Soil and air	Selection based on contaminants, overall soil conditions and overall targets for the area.	Combination of phytotypologies as mixed planting using all phytotechnology mechanisms while providing other ecosystem services.

Table 1.1 (continued)

15.Stormwater filter	Rhizofiltration	Nitrogen **Petroleum** **Chlorinated Sol-vents** Pesticides Metals Phosphorus POP's	Stormwater	Plants that thrive with substantial water and withstand periods of drought. Plants with deep tap roots and high evapotranspira-tion rates.	Plantings and soil remove and trap contaminants from stormwater. Extraction possible through harvesting.
16.Surface-flow constructed wet-land	Rhizofiltration	Nitrogen **Petroleum** **Chlorinated Sol-vents** Pesticides Metals Phosphorus POP's	Stormwater Wastewater Groundwater	Plants suitable for constructed wetlands. Selection based on contami-nants and overall targets for the area.	Water is directed through a series of planted marshes and engineered soil media to remove contaminants.
17.Subsurface gravel wetland	Rhizofiltration Phytostabilization	Nitrogen **Petroleum** **Chlorinated Sol-vents** Metals Phosphorus POP's	Stormwater Wastewater Groundwater	Plants suitable for constructed wetlands/ deeper rooting depth.	Contaminated water is treated by pumping the water slowly through subsurface gravel beds. Filtering through plant roots and soil media.
18.Floating wetland	Rhizofiltration	Nitrogen **Petroleum** **Chlorinated Sol-vents** Pesticides Metals Phosphorus POP's	Existing surface water bodies	Selection based on contami-nants and overall targets for the area.	Plantings installed on structures are floated on existing water bodies to filter contaminants out of the water

Typologies that specifically target the most common contaminants at gas stations are highlighted in bold letters. Rows with pattern overlays (1, 3, 4, 6, 7, 8, 9, 12, 15) indicate Kennen and Kirkwood's suggested nine phytotypologies for the land use category of gas stations and auto-repair shops (2015, pp. 266–267). Rows in green indicate the six phytotypologies explored in this design research project (4, 7, 9, 12, 13, 15)

[a]Eighteen phytotechnology planting types after Kennen and Kirkwood [4], pp. 201–244

[b](1) Petroleum hydrocarbons, pp. 65–94; (2) chlorinated solvents, pp. 94–103; (3) explosives, pp. 103–110; (4) pesticides, pp. 111–117; (5) persistent organic pollutants (POP's), pp. 118–123; (6) volatile organic compounds (VOC's), pp. 124–125; (7) nitrogen, pp. 126–131; 125–136; (8) phosphorus, pp. 131–135; (9) metals, pp. 136–179; salt, pp. 179–181; (10) radioactive isotopes, pp. 182–189; (11) air pollutants, pp. 189–198 [4]

[c]Contaminated sites should be screened for heavy metals that may still occur on gas stations. Specific remediation techniques may apply including conventional remediation

Sequence of order follows the referenced literature

Table 1.2 List of petroleum-tolerant plant species recommended for remediation with focus on indigenous North American plants within Plant Hardiness Zone 6a [18]

Plant species	
Herbaceous plants	*Andropogon gerardii*—Big bluestem *Bouteloua curtipendula*—Side oat grass *Bouteloua dactyloides*—Buffalo grass *Bouteloua gracilis*—Signal grass *Carex cephalophora*—Ovalhead sedge *Carex stricta*—Sedge *Elymus canadensis*—Canada wild rye *Elymus hystrix*—Bottlebrush grass *Festuca rubra*—Red fescue *Geranium viscosissimum*—Sticky geranium *Panicum virgatum*—Switchgrass *Agropyron smithii*—Western wheatgrass *Schizachyrium scoparium*—Little bluestem *Scirpus atrovirens*—Green bulrush *Solidago* ssp.—Goldenrod *Sorghastrum nutans*—Indiangrass *Triglochin striata*—Three-rib arrowgrass *Trifolium* spp.—Clover *Tripsacum dactyloides*—Eastern gamagrass *Typha* spp.—Cattail
Trees and shrubs	*Betula nigra*—River birches *Celtis occidentalis*—Hackberry *Cercis canadensis*—Eastern redbud *Fraxinus pennsylvanica*—Green ash *Juniperus virginiana*—Eastern red cedar *Morus rubra*—Red mulberry *Gleditsia triacanthos*—Honey locust *Pinus banksiana*—Jack pine *Populus deltoides*—Eastern cottonwood *Populus* spp.—Hybrid poplars *Pinus virginiana*—Virginia pine *Quercus macrocarpa*—Bur oak *Robinia pseudoacacia*—Black locust *Salix alaxensis*—Arrowhead *Salix nigra*—Black willow *Salix* spp.—Willows

List selected from Kennen and Kirkwood ([4], pp. 74–85)

1.3.4.3 Green and Blue Roof

Green and blue roofs evapotranspire water and minimize stormwater runoff and thus reduce the impact of surface pollutants. The *blue roof* provides short-term detention of rainfall and promotes evaporation without plants. This has the advantage of maximizing the evaporation rate in comparison to *green roofs*, while the latter has aesthetic and environmental benefits. Plants on *green roofs* are drought-resistant species and typically not selected for contaminant removal.

1.3.4.4 Interception Hedgerow

Another method of targeting contaminated groundwater is the *interception hedgerow*. This treatment is suitable for situations with a limited amount of space and therefore very applicable to gas stations in denser urban conditions. A single row of trees is planted, usually around the perimeter of a site and downgradient of the source of the contamination to prevent contaminated groundwater leaching off-site. Phreatophytes with deep ending root systems are recommended. 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 screen.

1.3.4.5 Degradation Bosque

A *degradation bosque* is very similar to an *interception hedgerow*. The same plants that are applicable to the hedgerow are expanded into a grid of trees. The grid of trees maximizes the effectiveness by ensuring that every available portion of the land being planted is targeted. Under the surface, the root systems of these trees become interconnected and are essentially in contact with the complete volume of soil in the root zone. The *degradation bosque* provides constant layers of activity through multiple rows of trees, contrary to the *interception hedgerow* which has only one layer.

1.3.4.6 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 spatial definition is needed. These two methods vary in 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 4 ft deep (120 cm). 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 develop their extensive root systems to find water. This provides the intrinsic ability to seek out contaminated water for mitigation.

1.3.4.7 Degradation Cover

The *degradation cover* is 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 0 to 5 ft deep

(0–150 cm). The predominant plants used for *degradation covers* are the same deep-rooted and drought-tolerant prairie grass species mentioned with the *degradation hedges*.

1.3.4.8 Airflow Buffer

This typology uses vegetation to trap particulate matter in the air on leaf surfaces and keep pollutants on-site. The contaminants are not degraded and are washed off the plants. Therefore, it is recommended to pair this phytotypology with other systems such as *stormwater filters*. Multilayered plantings and plant species with big leaves seem to be more successful in accumulating particular matter than others.

1.3.4.9 Stormwater Filter

Stormwater filters generally consist of plantings that tolerate an extreme amount of water as they are placed downgradient of impervious surfaces. There the contaminants are removed and immobilized by the plants and thus do not migrate off-site and pollute the groundwater. To maximize degradation, it is suggested to select a diverse plant palette that breaks down petroleum and produces high biomass. This will allow for a mixture of root types to target the contamination while having the capacity necessary for high rainfall events. Inorganics are also stabilized through *stormwater filters* and are prevented from leaching off-site. Plants will need to be harvested to remove the contaminants from the soil.

1.3.5 Plant Selection

The plants listed below are petroleum-tolerant plant species recommended for remediation with focus on indigenous North American Plants within Plant Hardiness Zone 6a [18]. Further selection is necessary following site-specific criteria, maintenance, and aesthetic principles.

1.4 Application of Phytotypologies at a Former Gas Station in Hadley, MA

1.4.1 Site Description and Analysis

The case study area is a former Getty gas station on Route 9 in Hadley, Western Massachusetts (USA). This gas station was selected because of the size and location. The small size of 12 acres (0.5 ha) is typical for smaller-scale gas station and exemplary for many abandoned gas stations due to the growing competition [2]. The exposed location at the entry of a town or city underpins the importance for cleaning up a derelict site and showcases new design models.

Hadley, MA, has an average low temperature of 20 °F (−6.7 °C) and an average high temperature of 78 °F (25.3 °C) [19]. The area falls within the Plant Hardiness Zone 6a (−20 to −15 °F; −28.9 to −26.1 °C) [18] and is approximately 600 ft (200 m) away from the Connecticut River as part of the Connecticut River watershed. It is located 60 ft (20 m) to an adjacent wooded marshland that connects to the River. The water table is 48–72 inches (120–180 cm) below ground. The prime soil in the area is fertile Hadley silt loam. On-site, the upper horizons are silty loams from 0 to 68 inches (0–173 cm) and loamy fine sands below with a high permeability. Land use activities that cause leaking of petroleum-related substances thus create a potential danger for the environment. Likely locations and quality of pollutants that exist in common gas stations were retrieved from the prevailing literature such as Kennen and Kirkwood (pp. cc [4]) because core samples of the soil itself could not be taken (Fig. 1.2). 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.

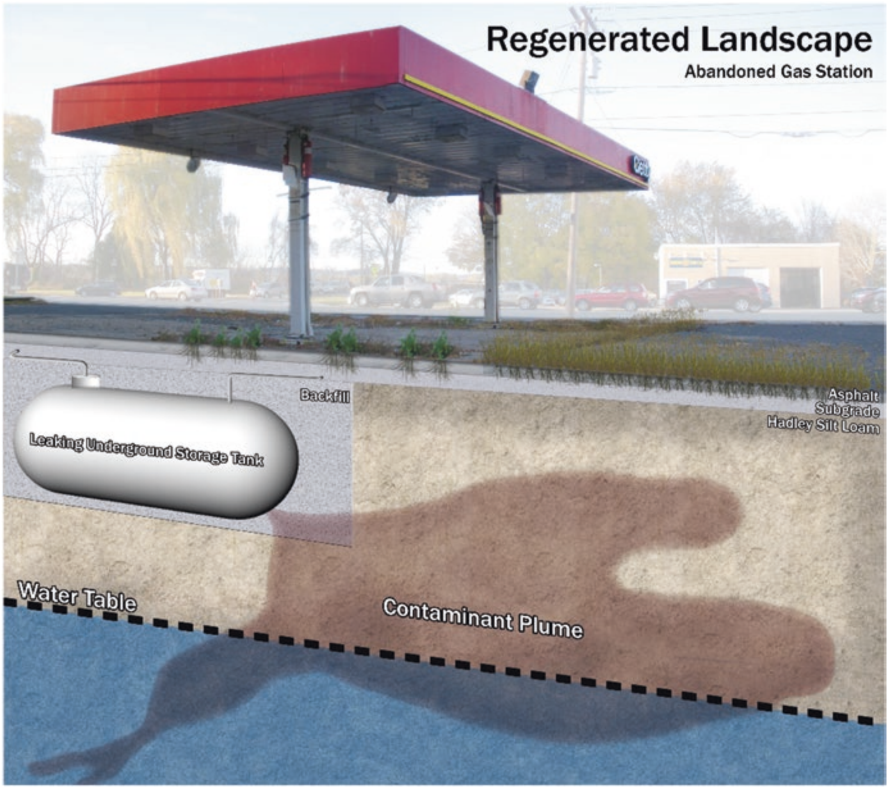

Fig. 1.2 Existing contamination—illustration of contaminations found on-site [7]

1.4.2 Overall Design Description and Considerations

The redesigned former gas station is a new public green space that invites visitors from the nearby recreational trail (Fig. 1.3). Safe road crossings on Route 9 make the place accessible. From there the visitors reach entry spaces that are secluded from the busy street and are invited to take a journey over a winding boardwalk to experience the diverse landscape elements that perform the cleansing of water and soils. The elevated boardwalk prevents physical contact with potentially harmful substances.

Many of the planting typologies that are applied in the design have tangible spatial qualities such as the *airflow buffer* and the *interception hedgerow* along the Road 9, the *degradation bosque* to the east, or the *green walls* that are attached to the roof structure of the former gas station. Other elements such as the *stormwater filter* create a network of vegetated swales that connects to the larger landscape and the adjacent wooded marshland.

The roof structure references the history of the site. 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 large overhead structure that serves as

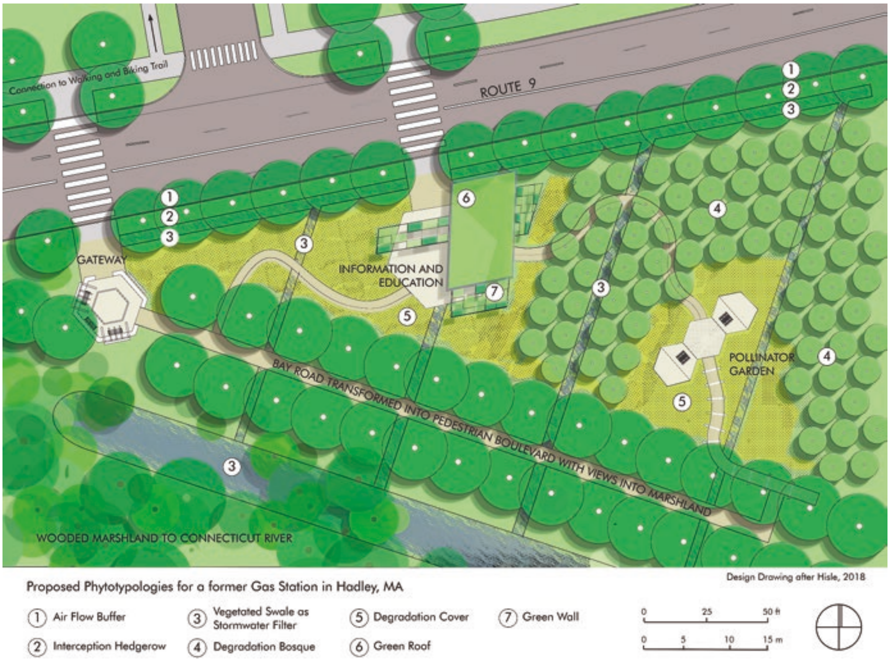

Fig. 1.3 Design plan—proposed phytotypologies for a former gas station in Hadley, MA. Drawing after Hisle [7]

shelter during fuel pumping was therefore retained and transformed with a *green roof* and *green walls*. It encourages a dialogue between the user and the landscape's past and present. 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 [5].

1.4.3 Selection and Application of Phytotypologies

Seven phytotypologies were selected for the project in Hadley, MA. These are *air-flow buffer*, *interception hedgerow,* stormwater *filter*, *degradation bosque, degradation cover*, *green roof, and green wall.* The plan and section illustrate the spatial relationship between the applied typologies. The typologies are described in a sequential order from the edge of the road, across the former gas station to the marshland from north to south (Figs. 1.3, 1.4, and 1.5). While it is helpful to distinguish typologies, the qualities can overlap and hybridize. For example, the *airflow buffer* along a busy street's edge can contain functions of an *interception hedgerow*. Another example is the *degradation bosque* that evolves into an *interception hedgerow* with a single or double row of larger trees to provide more spatial definition.

Airflow Buffer—A row of big-leafed trees and a layer of understory grasses with shrubs of different heights accumulates traffic-related particular matter from Route 9. Possible trees are *Fraxinus pennsylvanica* (green ash) or *Quercus rubra* (red oak).

Interception Hedgerow—A screen of robust and petroleum tolerant shrubs such as *Salix alaxensis* (feltleaf willow) - prevent contaminated groundwater leaching offsite. The interception hedgerow also serves as an *airflow buffer*.

Stormwater Filter—A vegetated swale treats contaminants that are washed off the street and the plants from the *airflow buffer*. It provides a buffer between Route 9 and the abandoned gas stations to prevent any further contamination from accessing the site.

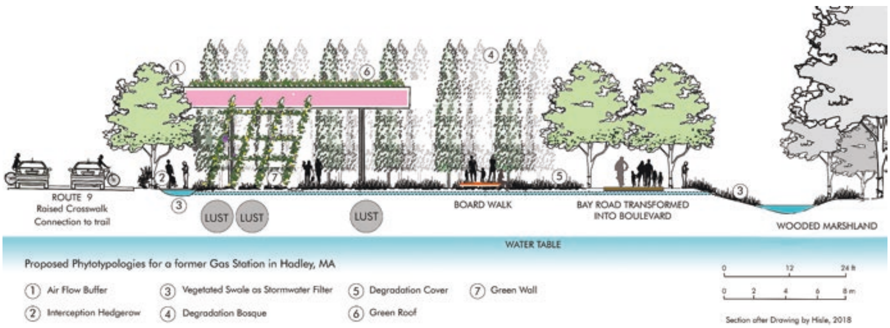

Fig. 1.4 Design section—proposed phytotypologies for a former gas station in Hadley, MA. Drawing after Hisle [7]