Acknowledgements
Thank you to Rebekah Dye, Andrea Parker and Jay Tsai for their contributions to this publication, to Ian Balcom for his advice and guidance, to Richard Reiss and Carina Molnar of City Atlas for supporting the project, to the farmers at La Finca del Sur in the South Bronx for opening their doors to using La Finca as a testing ground.

A special thank you to all supporters on kickstarter, who made the printing of this field guide and the soil testings at our field lab possible.
# TABLE OF CONTENTS

## SECTION I OVERVIEW

**VACANT LAND**  Growing a productive urban landscape on vacant land .................. 4

**COMMON CONTAMINANTS**  And how they got into our soil ................................. 8

**PHYTOREMEDIATION**  Using nature to clean your soil ...................................... 12

**BENEFITS AND LIMITATIONS**  Deciding if phytoremediation is right for you ... 16

*+ CASE STUDY I*  PRIVATELY OWNED SCRAP YARD, ARKANSAS .......................... 19

*DO IT YOURSELF*  Eight steps to create your remediation project .................... 20

*+ CASE STUDY II*  PRIVATELY OWNED RESIDENTIAL SITE, TEXAS ..................... 27

## SECTION II REFERENCE

**REFERENCE TABLE**  Common contaminants and their natural enemies .............. 28

**PLANT PROFILES**  Annuals .................................................................................. 32

  Perennials and small woody plants ............................................................... 34

  Trees and large woody plants ....................................................................... 36

**GLOSSARY** ........................................................................................................ 38

**ENDNOTES** ...................................................................................................... 40

**BIBLIOGRAPHY** ............................................................................................... 41

**RESOURCES**  And where to learn more ................................................................ 42
The post-industrial American city contains an abundance of vacant land within its boundaries, much of it abandoned by past industrial uses. Just as frequently, gaps of vacant lots dot the fabric of residential neighborhoods. On average, 15% of land in cities is vacant. In some cities this share is up to 45% of the land within municipal boundaries.\(^1\) The phenomenon of abandonment and vacancy is most frequently discussed in the context of shrinking industrial cities. Urban areas like Cleveland, Detroit and Philadelphia have experienced a decline in its industrial sector since the 1970s. As a result, an increasing number of residential and industrial properties in these cities were abandoned over the past few decades, often in central locations. Philadelphia, for instance, counts over 50,000 vacant properties within its city limits.\(^2\)

A study conducted by the Brookings Institution found that the phenomenon of vacant land is not only a problem of shrinking cities. For example, between 1980 and 1995 Phoenix, AZ grew in population by 55% and in land area by 30%, yet at the same time it reported 43% of its land as vacant.\(^3\) Many cities do not collect any information about vacant properties, leaving the hidden potential of the land unknown.

In his essay “terrain vague”, Ignasi de Sola-Morales Rubio describes the presence of urban vacant land as “internal to the city yet external to its everyday use.” “... they are foreign to the urban system, mentally exterior in the physical interior of the city, its negative image as much a critique as a possible alternative.”\(^4\) It is this possible alternative that evokes our imagination for dreaming up a future for these spaces, converting them once again into spaces that are internal to the city’s everyday use. Whether these spaces are private property or publicly owned, citizens can play a vital role in this process of re-engaging abandoned land in the course of daily life.
In New York City, the most populous of American cities, 7.1% of its land is currently vacant. This equals 11,000 acres of underutilized land, roughly the size of Manhattan. Enough land to grow vegetables and fruits for all of New York City's Public School children annually.

The national average of vacant land in cities is 15%, in some cities up to 45% of land is vacant. Much of it is possibly contaminated by previous industrial uses on the site or leftover building materials, especially lead-based paint. Utilizing this land for food production, recreation or housing is not safe unless, the soil and groundwater are free of toxins.

Remediation - typically in the form of excavation of contaminated soil is costly. Instead, these properties lie vacant for years... underutilized and toxic, their value dampened by sights of abandonment and potential contamination.

The following pages illustrate, how property owners can use these years to their advantage and initiate a slow, but cost-effective clean-up process using nature as their ally and collectively add 11,000 acres of productive landscape to the city's healthy environment. Half of all vacant lots in New York are smaller than 2,500 sf and owned by individuals. The costs associated with remediating lead contamination on a 2,500 sf lot through phytoextraction using Indian Mustard plants can be reduced to 10% of those using common methods of excavation and fill.

Percentage of vacant land in selected US cities

<table>
<thead>
<tr>
<th>City</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York</td>
<td>7.1%</td>
</tr>
<tr>
<td>Chicago</td>
<td>6.8%</td>
</tr>
<tr>
<td>Phoenix</td>
<td>42.6%</td>
</tr>
<tr>
<td>San Diego</td>
<td>14.2%</td>
</tr>
<tr>
<td>San Antonio</td>
<td>20.7%</td>
</tr>
<tr>
<td>Detroit</td>
<td>28.8%</td>
</tr>
<tr>
<td>Houston</td>
<td>7.0%</td>
</tr>
</tbody>
</table>
In New York City, the most populous of American cities, 7.1% of its land is currently vacant. These 11,000 acres roughly equal the size of Manhattan. The reuse of this land is vital to the city’s ability to grow. New York City needs housing to accommodate one million new inhabitants expected to move to the city by 2030. Many areas within the five boroughs have a large number of vacant lots, but not sufficient access to fresh produce. A growing interest in urban agriculture could potentially make use of these vacant lots, providing access to fresh produce in the city. Constructing housing and growing food are two of many potential futures for these 11,000 acres. However, much of this vacant land is potentially contaminated by previous industrial uses on these sites or left-over building materials, especially lead-based paint. Utilizing land for food production, recreation or housing is not safe unless the soil and groundwater are free of toxins.

Not all vacant land is contaminated and not all contaminated land is vacant. The Environmental Protection Agency (EPA) estimates that there are approximately 5 million acres of abandoned industrial properties in urban areas nationwide. In New York City, the contaminated land is estimated to amount to 7,000 acres. This is only an estimate, because many of these properties have never been tested. Half of all vacant lots in New York are smaller than 2,500 sq ft and 80% of all vacant lots are smaller than 5,000 sq ft. For the owners of these small properties the perception of contamination, the costs for testing and remediating, and the regulatory process involved can be daunting. As a result, many properties lie vacant and underutilized for years and neighbors have to live and work on blighted blocks.
Half of all vacant lots in New York are smaller than 2,500 sq ft.

VACANT LAND IN NEW YORK CITY
The EPA defines soil contamination as “either solid or liquid hazardous substances mixed with the naturally occurring soil. Usually, contaminants in the soil are physically or chemically attached to soil particles, or, if they are not attached, are trapped in the small spaces between soil particles.”

These substances stem from a variety of human activities and have different negative impacts on human health. One way of categorizing them is by element or compound, which has implications for the relevant techniques of phytoremediation. Potential contaminants in urban soils are listed below, with the most common described in the next few pages.

### ELEMENTS

Elements are made up of one type of atom. Some occur naturally in soil, but can be toxic at high concentrations. Elements of concern include:

- As Arsenic
- Al Aluminum
- Sb Antimony
- Ba Barium
- Be Beryllium
- Cd Cadmium
- Cr Chromium
- Co Cobalt
- Cu Copper
- Fe Iron
- Pb Lead
- Li Lithium
- Mn Manganese
- Hg Mercury
- Mo Molybdenum
- Ni Nickel
- Se Selenium
- Ag Silver
- Ti Thallium
- Sn Tin
- U Uranium
- V Vanadium
- Zn Zinc

### COMPOUNDS

Compounds are sets of elements bound together. Toxic compounds are often human made, for direct use or as a byproduct. Compounds of concern include:

- Benzidines/Aromatic amines
- Dioxins, Furans, PCBs
- Hydrocarbons
- Nitrosamines/ethers/alcohols
- Organophosphates and carbamates
- Pesticides
- Phenols/phenox acid
- Phthalates
- Radionuclides
- Volatile organic compounds

### Levels safe for these land uses:
(in parts per million)

- Commercial
- Residential
- Food Production
PAH Polyaromatic Hydrocarbons

Polyaromatic Hydrocarbons are over 100 chemicals, formed during the incomplete burning of many organic substances.

Why is PAH in our soil? PAHs are found in exhaust from motor vehicles and other gasoline and diesel engines, emission from coal-, oil-, and wood-burning furnaces, cigarette smoke; general soot and smoke, and cooked foods, especially charcoal-broiled; in incinerators, coke ovens, and asphalt processing and use.

Risk to human health:
• red blood cell damage leading to anemia
• suppresses the immune system
• known to cause cancer

* levels for Benzo[a]pyrene

PCB Polychlorinated Biphenyls

Polychlorinated Biphenyls are man-made organic chemicals, manufactured in the United States between 1929 and its ban in 1979.

Why is PCB in our soil? PCBs were used in industrial and commercial products including electrical, heat transfer, and hydraulic equipment; as plasticizers in paints, plastics, rubber products, and other industrial applications. Today, PCBs can be released into the soil due to improper disposal of PCB-containing products or leaks from electrical transformers.

Risk to human health:
• affects reproductive system, immune system, nervous system
• known to cause cancer

TCE Trichloroethylene

Trichloroethylene is a non-flammable, colorless liquid that belongs to a group of chemicals known as “Volatile Organic Compounds” (VOCs).

Why is TCE in our soil? It is used in adhesives, paint and spot removers, and as a solvent for degreasing engine parts. It has also been used in food production, dry cleaning, medicine (as an anesthetic) and film cleaning. Its widespread use since the 1920s continues today, yet use has declined in the last decade.

Risk to human health:
• dizziness or sleepiness
• short term: symptoms similar to alcohol intoxication, can lead to death
• long term: liver and kidney cancer, leukemia,
• non-Hodgkin lymphoma
Cadmium is a soft bluish-white metal and occurs often as a by-product of zinc production.

**Why is cadmium in our soil?**
Cadmium can be found in many industry and consumer products, mainly batteries, pigments, metal coatings, and plastics. It enters our soil and water through the disposal of these products. It enters our air through the burning of coal and household waste.

**Risks to Humans:**
- can cause kidney damage and fragile bones

**Chromium** is a steel-grey hard metal that can be found in the environment in chromium-containing rocks.

**Why is chromium in our soil?**
Chromium compounds are used for chrome plating, the manufacturing of dyes and pigments, leather tanning and timber preservation among other things. Cement contains chromium. Emissions from automobile brake lining and catalytic converters containing chromium lead to higher levels of chromium in the air and soil near busy roads.

**Why is lead in our soil?**
Prior to 1978 most fuels contained lead. Cars exhaust lead oxide, which would then filter into the soil near heavy trafficked roads. Lead-based paint, also phased out now was used until the late 1970s for the exterior of buildings. As the paint got old, chips containing lead would fall off and mix into the soil. Lead is also used in construction and various industries.

**Risks to Humans:**
- toxic to the heart, bones, intestines, kidney, reproductive and nervous system
- can cause learning and behavior disorders
- irritation to the nose and skin,
- itching, nosebleed, sneezing
- can cause cancer, liver damage
**Arsenic (As)**

**Arsenic** is a chemical element that occurs in many minerals usually in conjunction with sulfur and metals.

**Why is arsenic in our soil?**

Mining, smelting of non-ferrous metals and burning of fossil fuels are the major industrial processes that contribute to arsenic contamination of air, water and soil. The use of arsenic in pesticides and in the preservation of timber has also led to contamination of the environment. Especially fruit tree orchards are often affected by arsenic contamination through the use of pesticides.

**Risks to Humans:**

- can cause cancer in the skin, lung, bladder and kidney

<table>
<thead>
<tr>
<th>Mining</th>
<th>Pesticides</th>
<th>Treated Lumber</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 ppm</td>
<td>16 ppm</td>
<td>13 ppm</td>
</tr>
</tbody>
</table>

**Mercury (Hg)**

**Mercury** is an extremely rare metal that occurs in deposits throughout the earth’s crust.

**Why is mercury in our soil?**

Mercury enters our air, water and soil through the waste stream of products that contain mercury such as old thermometers, barometers, batteries, fluorescent lightbulbs, paint, electrical switches and tooth fillings. Coal fired power plants used to emit mercury. Some mercury compounds are also found in fungicides.

**Risks to Humans:**

- damage to the brain, kidney and developing fetus
- skin rashes and effects on the lungs and eyes

<table>
<thead>
<tr>
<th>Mining</th>
<th>Pesticides</th>
<th>Treated Lumber</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.8 ppm</td>
<td>.81 ppm</td>
<td>0.18 ppm</td>
</tr>
</tbody>
</table>

**DDT (Pesticides)**

**DDT** is one of the most well-known pesticides. Pesticides are chemical substances intended for preventing, destroying, repelling or mitigating any pest. DDT was banned in 1972, but pesticides containing other toxic substances are still in use today.

**Why is DDT in our soil?**

Over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species. Pesticides leak from production facilities or storage tanks, run off fields when overused, or are sprayed and discarded.

**Risk to human health:**

- premature birth and low birth weight
- breast cancer
- impaired child neural development

<table>
<thead>
<tr>
<th>Mining</th>
<th>Pesticides</th>
<th>Treated Lumber</th>
</tr>
</thead>
<tbody>
<tr>
<td>47 ppm</td>
<td>.17 ppm</td>
<td>0.0033 ppm</td>
</tr>
</tbody>
</table>
Phytoremediation is the in-situ (onsite) use of plants to reduce contamination of soil, sediments, surface water or groundwater. By harnessing the natural capabilities of plants, we can remove, degrade or stabilize contaminants. It can be a low-cost, but time-intensive alternative to traditional remediation on sites where toxins are at shallow depth. It can also be an effective approach to reducing the leaching of contaminants through soil or groundwater, and can be used in combination with other remediation techniques.

Most phytoremediation processes make use of the everyday plant process of transpiration, in which water and nutrients are brought up from the soil through the roots, used and distributed through trunks and branches, and evaporate through pore-like stomata on the leaves. Certain plants will take up particles of contaminants through this process. In other plants, the active soil life in the root zone degrades contaminants.

Phytoremediation has been successfully applied to a variety of sites including pipelines, industrial and municipal landfills, agricultural fields, wood treating sites, military bases, fuel storage tank farms, gas stations, army ammunition plants, mining sites and residential sites. Field studies have included the remediation of heavy metals, radionuclides, chlorinated solvents, petroleum hydrocarbons, polychlorinated biphenyls (PCBs), pesticides and explosives.10
Contaminants get into soil from accidental leaks and spills, deliberate dumping, or accumulated contaminated dust or precipitation. Once in the soil, contaminants may evaporate, bind to soil particles, or migrate downward. Groundwater flow through the soil can direct a plume of contamination. Over time, particles of contamination will spread through the soil, potentially contaminating drinking water supplies.
PHYTOEXTRACTION: Plants take up contaminants, mostly metals, metalloids and radionuclides, with their roots and accumulate them in large quantities within their stems and leaves. These plants are also called hyperaccumulators.

PHYTODEGRADATION: Plants take up and break down contaminants through the release of enzymes and metabolic processes such as photosynthetic oxidation and reduction. In this process organic pollutants are degraded and incorporated into the plant or broken down in the soil.

PHYTOVOLATILIZATION: Some plants take up volatile contaminants and release them into the atmosphere through transpiration. The contaminant is transformed or degraded within the plant into a less toxic state and then released into the air. Sometimes, the contaminant is released as is and then degraded by the sun.

RHIZODEGRADATION: In some cases microbes in the soil break down contaminants into a less toxic state. In other cases these microbes can completely destroy the contaminant. The root zones of certain plants create an environment that assists this process. Therefore it is also called plant-assisted degradation.

RHIZOFILTRATION: Some plant roots can filter contaminated water by adsorbing the contaminants into their root and plant tissue. Similar to phytoextraction, the plants themselves may become contaminated and have to be disposed as special waste.

PHYTOSTABILIZATION: Some plants can sequester or immobilize contaminants by absorbing them into their roots and releasing a chemical that converts the contaminant into a less toxic state. This method limits the movement of contaminants through erosion, leaching, wind or soil dispersal. It is often referred to as a „green cap“.

PHYTOREMEDIATION
Using nature to clean your soil
Improved air quality and reduction of stormwater run-off are among the additional ecological benefits of planting on underutilized sites. In some cases, phytoremediation can eliminate most or all the pollutants from a site permanently instead of transporting the problem to a landfill. Because plants have the ability to eliminate certain contaminants completely, phytoremediation often offers a more sustainable alternative to traditional brownfield remediation. In other cases it can be used as an effective stop-gap measure to contain the spreading of contamination by erosion or wind, especially when there is risk of contaminants leaching into groundwater.

Previous projects have demonstrated cost savings of 50% for the extraction of heavy metals and up to 80% for the removal of petroleum hydrocarbons from soil in comparison with traditional methods. In particular, the technology-intensive excavation and removal of soil can be costly if large equipment is needed. Phytoremediation uses simple landscaping equipment supplemented by sophisticated monitoring. The amount of plants that are disposed is much less than the amount of soil disposed in traditional remediation, and therefore disposal costs are greatly reduced. These costs can be further reduced when labor is provided by volunteers, community groups or property owners themselves.

One of the greatest limitations to using phytoremediation is time. Reducing the level of contamination in soil may take several planting cycles or it may take several years for trees to develop roots deep enough to treat deeper levels of contamination. The monitoring and maintenance of the plants also require a substantial amount of time spent on the site on a regular basis during growing season. The depth of the contamination may be another limitation. Different plants have different root lengths and often may not be able to reach deep enough to effectively remove all contamination from the soil.
EXCAVATION AND FILL
$20-40/sq ft

EXCAVATE

FILL

TOXIC WASTE

CLEAN SOIL

EXCAVATE

FILL

PHYTOEXTRACTION
$5-20 /sq ft

HARVEST > COMPOST > TOXIC WASTE

TEST PLANT

EXTRACT

TEST REPLANT

EXTRACT

TEST REPLANT

EXTRACT

YEAR 1

YEAR 2

YEAR 3
In some cases, the quality of the existing soil or extensive shade on the site can make it difficult to grow the desired plant species. Soil quality can be especially challenging, since abandoned sites often contain a substantial amount of garbage or debris and little nutrients. Another risk with phytoremediation is the potential for contaminants to enter the food chain. This risk is minimal in urban areas, where chances are low that animals consume the contaminated plants, but should be considered and planned for in rural areas.

Supporting phytoremediation projects is a good strategy for cities. In addition to the increased value the vacant property may eventually gain, the process of testing, planting, and monitoring the progress under the supervision of experts builds a sense of ownership and investment among community groups or property owners involved in this multi-year process. The interim presence of a planted area on a development site might not only be favored by communities over truckloads of contaminated soil being hauled through the neighborhood, it also reduces the short-term risk on the surrounding area that these trucks impose and adds value to the community at large.

Prior to starting a phytoremediation project, you should make sure that there is no pressing need to develop the site quickly and that you are willing to commit several seasons to the project. While much of the work can be done by unskilled labor, such as the planting, maintenance and harvesting of the plants, you should make sure to get a team of experts involved who can advise on phytotechnologies, precaution measures with contaminated soil, soil science, plant biology, local regulations and cost evaluations.
CASE STUDY I

PRIVATELY OWNED SCRAP YARD, ARKANSAS

Automotive parts, scrap metal and packaging materials contaminated this site for years. Petroleum hydrocarbons and PCBs were found to a depth of 2 feet. In April 2001 one-foot tall red mulberries were planted on a 2x2 foot grid. Bermuda grass seeds were then spread between the trees. Soil samples were taken after 18 months and again after 28 months. Both TPH and PCB levels decreased to acceptable low occupancy levels. The total project costs for the 2 acre site was approximately $140,000. (Source: EPA Project Database for Phytotechnology)
RESEARCH AND TESTING
You can understand if and what type of contaminants might be present on your site and what to test for by researching previous activity and land uses on the site and in the surrounding area. Gather soil samples from at least 4 different areas in every 400 sq ft of space. Samples should come from approx. 1-36 inches below the surface based on your initial research on how deep contamination may be on your site. It should not contain any gravel, grass, trash, etc. At a minimum you want to collect samples from three different areas on your site to allow for variations in the data.

Several universities provide inexpensive soil testing services (between $10 and $35 for heavy metal tests). Fill a ziplock bag with your soil and send it to their lab together with information about your site. Testing the soil for nutrients, in addition to heavy metals, will assist you in assessing whether or not plants can thrive on your site. Testing your site for organic pollutants requires consulting a commercial lab and is more expensive. The Environmental Protection
Agency (EPA) developed Target Compound and Target Analyte Lists (TCL/TALs), which are typically used for a baseline overview of all contaminants that are regulated by the EPA. The EPA collects data on prices for these tests. A full sampling of TCL/TAL tests can cost approximately $800 for one soil sample.

**STRATEGY AND BUDGET**

From the test results, determine if and how to remediate contaminants with plants. Contact an expert for advice. Several experts with experience in phytoremediation projects are listed in the back of this publication. They will be able to help you choose the right plant type, assess the risk of contamination and potential precaution measures to be taken. If you are new to gardening or farming, get advice on the maintenance and care for plants. You should also contact the regulatory agency in your city to discuss local requirements. They will be able to help you with expertise in cleanup target levels and the approval process for redevelopment of your site.
Your research up to this point should allow you to reasonably estimate the time and costs involved in a phytoremediation project. If your strategy involves phytoextraction, you should collect information upfront on the potential testing and disposal of the plants after harvesting. Additional testing throughout the process to monitor progress can also add to the costs. If you have to pay for labor to maintain and monitor the plants, calculate this cost for a minimum of what you estimate the timeframe for your project will be. Make sure to include tools and equipment to prepare the soil, to irrigate the plants, and to keep them free of weeds if you don’t already have these available. Plants grown from seeds are typically cheaper than those that require propagating from stem cuttings or bulbs. Determine whether location and orientation of the site would allow plants to thrive. The availability of water on or near the site will be important in maintaining the plants.

**PLANTING AND GROWING**
Make sure to purchase seeds, bulbs and cuttings
early enough to start growing after the last frost. When selecting plants for a remediation project, additional care should be taken to not introduce invasive species in areas where those species would have the tendency to hinder growth of other native plants (maps on pages 30-35 indicate the native and hardy zones for select plants). Research individual instructions for growing your plants, but keep in mind that you want to use them to eliminate contaminants from the soil, so you will likely plant more densely than normal, in a concentration that will cover the entire soil surface. Based on root depth and density of leaves, you want to combine different species to produce a sufficient density of roots below the surface while allowing plants space to grow above ground.

Maintain and monitor your site like you would any other garden. Persistent weeding will help your plants prevail and once your plants have reached a certain size and are not threatened by weeds, some weeds can actually be helpful in mitigating soil erosion.
Regular water is important, and you may want to give your plants a boost occasionally with an organic fertilizer.

**HARVEST AND DISPOSE**

After about 14 weeks, you should be able to harvest your annual plants. Since you will not consume these plants, harvest here can occur later than usual, when the plants start wilting and finished their growth period. Remove them with their entire root. This will also give you a chance to see how deep into the soil they reached. Save some seeds for the next growing cycle. If your climate allows, this could be right away. Perennial plants and trees such as willow or poplar do not need to be harvested every year. They will continue to grow their roots and become more effective remediators over the years.

Contact a hazardous waste disposal contractor and ask them to test your harvested plant material. They will use what is called a TCLP method that determines, whether your harvested plants would run the risk...
of leaching contaminants back into the ground and further into groundwater once disposed at a landfill. If the test is positive, they have to be disposed at a hazardous waste landfill in a container. This is not very likely, but be prepared to bear the costs of it. It also means that your remediation is very successful.

If you planted plants to degrade organic compounds, you should test the plant tissue to be sure that the compounds are fully degraded and no other toxins have accumulated within the plant before composting them. At the end of the growing season, re-test the soil to understand the improvements you have made and to make adjustments to your strategy. Depending on the level of contamination, you will have to repeat this planting process over several years.

Once your tests verify that you have reached the desired clean up target, you should contact your local government agency to get your property acknowledged as free of contamination. You may have to hire a contractor accepted by your local agency to do the final testing.
The second part of this publication serves as a reference to be used in a phytoremediation project. The first two tables list the most common contaminants found in urban soil and the maximum levels of contamination for three different kinds of uses.

“Unrestricted use” includes growing food or raising live-stock for human consumption. These uses allow an absolute minimum level of contamination. Anything above these levels is subject to some use restriction.

“Residential use” includes single-family housing, active recreational uses and gardening. Multi-family housing is referred to as “restricted residential use”. While higher levels of contamination are allowed here, there are limits to related uses such as gardening or playgrounds. The numbers in the following tables refer to unrestricted residential use.

“Commercial uses” include retail as well as office spaces, but not industrial uses. Passive recreational uses such as parks also fall in this category.

The values are measured in parts per million (ppm), which means that for every million parts of soil by dry weight, there would be 1 part of the contaminant. These values are the same as results reported in mg/kg (milligrams of contaminant per kilogram of soil). In some cases ppb (1 part of contaminant per billion parts of soil) is used as a measure. There is no single standard that defines acceptable levels of contamination in soil. The numbers in these tables are based on the New York State soil cleanup objectives. The tables also list a variety of plants that can remediate them and the process that they apply. A selection of these plants is described in more detail on the following pages. These help to understand the origin of these plants, how to maintain them and how deep their roots typically grow.
CASE STUDY II  
PRIVATELY OWNED RESIDENTIAL SITE, TEXAS 
After removing a deck in a residential backyard, the owner found arsenic of 30 to 40 ppm in the soil and initiated a clean up with hyperaccumulative fern. The fern was planted from pots and fertilized, irrigated and harvested by the owner of the property. After one growing season, the concentration of arsenic in the soil was reduced to 20 ppm. The cost for this pilot project of approximately 400 sq ft was $3,000 - $4,000.
(Source: EPA Project Database for Phytotechnology)
# Reference Table

**Common urban contaminants and their natural enemies**

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Maximum Levels (in parts per million)</th>
<th>Safe To Use For:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ag</strong> Silver</td>
<td>1500 ppm</td>
<td>36 ppm</td>
</tr>
<tr>
<td><strong>As</strong> Arsenic</td>
<td>16 ppm</td>
<td>16 ppm</td>
</tr>
<tr>
<td><strong>Cd</strong> Cadmium</td>
<td>9.3 ppm</td>
<td>2.5 ppm</td>
</tr>
<tr>
<td><strong>Cr</strong> Chromium</td>
<td>400 ppm</td>
<td>36 ppm</td>
</tr>
<tr>
<td><strong>Cu</strong> Copper</td>
<td>270 ppm</td>
<td>270 ppm</td>
</tr>
<tr>
<td><strong>Hg</strong> Mercury</td>
<td>2.8 ppm</td>
<td>0.81 ppm</td>
</tr>
<tr>
<td><strong>Ni</strong> Nickel</td>
<td>310 ppm</td>
<td>140 ppm</td>
</tr>
<tr>
<td><strong>Pb</strong> Lead</td>
<td>1000 ppm</td>
<td>400 ppm</td>
</tr>
<tr>
<td><strong>Zn</strong> Zinc</td>
<td>10,000 ppm</td>
<td>2200 ppm</td>
</tr>
</tbody>
</table>

**ANNUALS** plant seeds

<table>
<thead>
<tr>
<th>Native</th>
<th>Native</th>
<th>Native</th>
</tr>
</thead>
</table>

**Degradation**

- Brassica juncea (Indian mustards)
- Brassica oleracea (Wild Cabbage)
- Cerastium arvense (Field chickweed)
- Helianthus annuus (Sunflower)
- Lupinus albus (White lupine)
- Medicago sativa (Alfalfa)
- Thlaspi caerulescens (Alpine Penny cress)

**Extraction**

**Stabilization**

**Volatile**
<table>
<thead>
<tr>
<th>PERENNIALS</th>
<th>TREES</th>
</tr>
</thead>
<tbody>
<tr>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PERENNIALS</th>
<th>TREES</th>
</tr>
</thead>
<tbody>
<tr>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PERENNIALS</th>
<th>TREES</th>
</tr>
</thead>
<tbody>
<tr>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
</tr>
</tbody>
</table>
# REFERENCE TABLE

## Common urban contaminants and their natural enemies

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Maximum Levels (in parts per million)</th>
<th>Safe To Use For:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BTEX</strong> Benzene, Toluene, Ethylbenzene, Xylenes</td>
<td>390 ppm</td>
<td>30 ppm (values for Ethylbenzene)</td>
</tr>
<tr>
<td><strong>C_{10}H_{8}</strong> Naphthalene</td>
<td>500 ppm</td>
<td>100 ppm</td>
</tr>
<tr>
<td><strong>CIO^4^-</strong> Perchlorate</td>
<td>~72 ppm</td>
<td>(no official values)</td>
</tr>
<tr>
<td><strong>DDT</strong> Dichlorodiphenyltrichloroethane</td>
<td>47 ppm</td>
<td>1.7 ppm</td>
</tr>
<tr>
<td><strong>MTBE</strong> Methyl tertiary butyl etherether</td>
<td>500 ppm</td>
<td>62 ppm</td>
</tr>
<tr>
<td><strong>PAH</strong> Polycyclic aromatic hydrocarbons</td>
<td>1 ppm</td>
<td>1 ppm</td>
</tr>
<tr>
<td><strong>PCB</strong> Polychlorinated biphenyls</td>
<td>1 ppm</td>
<td>1 ppm</td>
</tr>
<tr>
<td><strong>TCE</strong> Trichloroethylene</td>
<td>200 ppm</td>
<td>10 ppm</td>
</tr>
<tr>
<td><strong>TPH</strong> Total Petroleum Hydrocarbons</td>
<td>~100 ppm</td>
<td>(no official values)</td>
</tr>
</tbody>
</table>

### Natural Enemies

- Curcubita sp. Pumpkin
- Helianthus annuus Sunflower
- Medicago sativa Alfalfa
- Trifolium pratense Red Clover
- Trifolium repens White clover
- Cynodon dactylon Bermuda grass

### Contaminants

- Methyl tertiary butyl etherether (MTBE)
- Trichloroethylene (TCE)
- Polycyclic aromatic hydrocarbons (PAH)
- Polychlorinated biphenyls (PCB)
- Trichloroethylene (TCE)
- Total Petroleum Hydrocarbons (TPH)

### Natural Methods

- Degradation
- Extraction
- Stabilization
- Volatilization
<table>
<thead>
<tr>
<th>PERENNIALS</th>
<th>TRES</th>
<th>plant starts</th>
<th>plant starts</th>
</tr>
</thead>
<tbody>
<tr>
<td>native</td>
<td>native</td>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
<td>native</td>
<td>native</td>
</tr>
<tr>
<td>native</td>
<td>native</td>
<td>native</td>
<td>native</td>
</tr>
</tbody>
</table>

**Native Plants**

- *Festuca arundinacea*: Tall Fescue
- *Lemna minor*: Duckweed
- *Panicum virgatum*: Switchgrass
- *Phanerochaete chrysosporium*: White rot fungus
- *Rosa spp.*: Paul’s Scarlet Rose
- *Solidago hispida*: Hairy Goldenrod
- *Liquidambar styraciflua*: American Sweet Gum
- *Morus rubra*: Red Mulberry
- *Pinus taeda*: Loblolly Pine
- *Populus deltoides x P. nigra*: Hybrid Poplar
- *Robinia pseudoacacia*: Black Locust
- *Salix sp.*: Willow

**Native Trees**

- *Morus rubra*: Red Mulberry
- *Festuca arundinacea*: Tall Fescue
- *Lemna minor*: Duckweed
- *Panicum virginatum*: Switchgrass
- *Phanerochaete chrysosporium*: White rot fungus
- *Rosa spp.*: Paul’s Scarlet Rose
- *Solidago hispida*: Hairy Goldenrod
- *Liquidambar styraciflua*: American Sweet Gum
- *Morus rubra*: Red Mulberry
- *Pinus taeda*: Loblolly Pine
- *Populus deltoides x P. nigra*: Hybrid Poplar
- *Robinia pseudoacacia*: Black Locust
- *Salix sp.*: Willow
**PLANT PROFILES**

**Brassica juncea**
*Indian mustard*

This species is an excellent accumulator, but can become weedy or invasive if allowed to seed. Species used for different contaminants include Rapeseed Plant (B. napus) and Ragweed (B. oleracea).

**Helianthus annuus**
*Sunflower*

The sunflower’s deep roots make it effective at reaching deep contaminants. Its familiar form and flowers make it a popular choice for publically visible projects.

**Curcurbita sp.**
*Pumpkin*

These familiar vegetable crops are not edible when used for phytoremediation. Related selections used for different contaminants include Zucchini (C. pepo).
Annual plants live for one growing season, and are generally started from seed in the spring.

*Triticum aestivum*  
Wheat

*Trifolium pratense*  
Red Clover

*Medicago sativa*  
Alfalfa

This familiar staple crop is *not* edible when used for phytoremediation.

This common forage and cover crop has become naturalized through much of North America. Related species used for different contaminants include Pink Clover (*T. hirtum*) and White Clover (*T. repens*).

Another forage and cover crop, alfalfa’s deep roots get down to deeply contaminated soils.
PLANT PROFILES

Perennials and small shrubs

*Eichhornia crassipes*
Water Hyacinth

*Artemisia vulgaris*
Mugwort

*Solidago hispida*
Hairy Goldenrod

Water Hyacinth’s fast growth habit makes it both very effective at accumulating toxins out of water bodies, and very invasive - this should only be used in isolated water bodies.

Long used as a medicinal herb, this European native has colonized many an urban vacant lot. Its easy propagation make it an inexpensive alternative.

Not always readily accessible in the trade - check native plant nurseries for local availability. Related species used for different contaminants include *S. rugosa.*
Perennial plants live for two or more growing seasons and are generally grown in small pots, from cuttings or division, before planting in the ground.

- **Hydrangea macrophylla**
  - French Hydrangea
- **Rosa sp.**
  - Paul’s Scarlet Rose
- **Festuca ovina**
  - Blue Sheep Fescue

A field of this popular ornamental Hydrangea could change the perception that phytoremediators have to be weedy.

Paul’s Scarlet is a vigorous climbing rose - it should be provided with a trellis or other structure to grow on.

Other grasses used for different contaminants include Crested Wheatgrass (Agropyron cristatum), Highland Bent Grass (Agrostis castellana), Tall Fescue (Festuca arundinacea).
Willow is an easy to grow and broadly effective phytoremediator. Related species used for different contaminants include Almond Willow (Salix triandra) and Weeping Willow (Salix babylonica).

Nitrogen-fixing Black Locust is a scrappy pioneer species that can survive in marginal sites and soils.

Red Mulberry's support diverse fungal and bacterial communities in the soil that are effective at degrading organic contaminants.
Trees can reach deep contamination as they mature. They can be planted inexpensively as bare-root whips, available in nurseries and seed catalogs.

**Taxodium distichum**

*Bald Cypress*

Bald Cypress, a swamp species, can transpire large quantities of water, which can prevent migration of some contaminants to

**Pinus taeda**

*Loblolly Pine*

Fast-growing Loblolly Pine is commonly used in plantation forestry, so is easy to source for mass plantings.

**Populus deltoides x P. nigra**

*Hybrid Poplar*

Eastern cottonwood (P. deltoides) also performs phytoremediation, but grows less quickly and addresses fewer contaminants.
GLOSSARY

**ABSORPTION:** The process of one substance actually penetrating into the structure of another substance.\(^{13}\)

**ADSORPTION:** The physical process that occurs when liquids, gases, or suspended matter adheres to the surfaces of, or in the pores of, an adsorbent material like plants.\(^{14}\)

**BROWNFIELD:** A parcel of urban land that is not being used to its economic, social or ecological potential because of real or perceived contamination.

**CONCENTRATION:** The amount of a specified substance in a unit amount of another substance typically measured in parts per million (ppm) or miligram per kilogram (mg/kg)

**CONTAMINATION:** Substances at levels of concentration hazardous to living things and/or ecologies.

**COMPOUNDS:** Substances made up of two or more types of atoms.

**DEGRADATION:** The act or process of breaking down a molecule into smaller parts.

**ELEMENTS:** Substances made of one type of atom that cannot be broken down further by chemical means.

**ENZYMES:** Proteins in living things that catalyze chemical reactions.

**EXTRACTION:** The removal of a substance from a substrate by chemical or mechanical action.

**GROUNDWATER:** Water that exists in the pore spaces and fractures in rock and sediment beneath the Earth's surface.\(^{15}\)
HYPERACCUMULATORS: Plants that extract inordinate amounts of substances from soils with high concentrations of these substances.

IMMOBILIZATION: The fixation of an object in place. In Phytostabilization, contaminants are immobilized, reducing their danger to the environment.

LEACHING: A process through which a substance moves through soil typically mobilized by rain or similar addition of water.

MICROBES: A microscopic organism. Soil microbes gather around plant roots in order to ingest the dead plant materials.

NITROGEN FIXATION: In the rhizosphere of certain plants, soil bacteria pull nitrogen gas out of the air and turn it into a form usable by plants.

REMEDIAITON: The removal of contaminants to a concentration deemed safe for designated activities.

RHIZOSPHERE: The area of soil adjacent to plant roots that exhibits high microbial activity.\footnote{16}

TRANSPIRATION: The process of water traveling through a plant, from intake by roots to volitization off of leaves.

VOLATILIZATION: The phase conversion of a substance from a liquid to a gas.
2 www.planphilly.com/abandoned-city
3 Pagano and Bowman
5 www.brownfieldscenter.org/big/faq.shtml
6 www.epa.gov/superfund/students/wastsite/soilspil.htm
7 www.eco-usa.net/toxics/chemicals/heavy_metals.shtml
8 www.atsdr.cdc.gov/substances/ToxChemicalClasses.asp
9 www.dec.ny.gov/regs/15507.html
11 Ibid.
12 www.dec.ny.gov/regs/15507.html
13 EPA
14 Ibid.
15 www.tulane.edu/~sanelson/geol111/groundwater.htm
16 EPA

________________________________________
Brooklyn College, Environmental Science Analytical Center: Soil Testing Brochure (Department of Geology)  www.brooklyn.cuny.edu/pub/departments/esac/1535.htm


New York City Department of City Planning (Land Use Summary, 2007)


If you want to test your soil:
Many university labs offer inexpensive soil testing services for heavy metals. Listed below are a few:
University of Massachusetts Amherst www.umass.edu/soiltest/
Brooklyn College www.brooklyn.cuny.edu/pub/departments/esac/1535.htm
Cornell University soilhealth.cals.cornell.edu/
The EPA collects price information from contractors for testing services www.epa.gov/superfund/programs/clp/prices.htm and also a list of firms that perform tests: www.epa.gov/superfund/programs/clp/lablist.htm
Berkeley’s ecology center provides a list of labs in California: www.ecologycenter.org/directory/

If you want to know more about contaminants:
You can check out Eco-USA, a repository for information on contaminants and superfund sites: www.eco-usa.net/toxics/chemicals/index.shtml
or the resources on the Environmental Protection Agency’s website: www.epa.gov/pesticides/health/human.htm
and levels of contamination of soil that are acceptable for different uses in different states and countries at www.cleanuplevels.com

If you want to learn about your plant choices:
The USDA’s Plants Database has standardized information on plant ranges and characteristics plants.usda.gov.
The Lady Bird Johnson Wildflower Center has information about the propagation and wildlife value of native plants: www.wildflower.org
Ask your local nurseryperson about growing particular plants in your area.
If you want to research other phytoremediation studies:
The EPA maintains a collection of ongoing and completed projects at various scales including international examples at www.clu-in.org/products/phyto/

If you want to find out more about hazardous waste:
The website Environment, Health and Safety Online gives useful answers to the most common questions regarding Toxicity Characteristic Leaching Procedure(TCLP) to identify hazardous waste www.ehso.com/cssepa/TCLP.htm

If you want to contact someone who has experience with phytoremediation:

Ian Balcom, PhD
Assistant Professor of Environmental Toxicology and Chemistry, Department of Natural Sciences
Lyndon State College, VT
phone: 802-626-6247
ian.balcom@lyndonstate.edu

Dr. Lee Newman
Assistant Professor of Biotechnology and Phytoremediation, Environmental and Forest Biology
SUNY - College of Environmental Science and Forestry, Syracuse NY
phone: 315-470-4937
lanewman@esf.edu

Steven A. Rock
US EPA
phone: 513-569-7149
rock.steven@epa.gov
There is a growing number of vacant lots in post-industrial American cities, many of which are contaminated by their industrial past. Remediation of toxic soil contaminated with heavy metals, hydrocarbons or PCBs is costly. Owners of small properties often shy away from these costs and complications and leave their sites vacant, underutilized and undervalued for years. The lack of action often affects the value of surrounding properties and the health of a community at large.

This field guide is designed for individual property owners and community groups to initiate a conversation about how to convert this enormous land potential into a productive urban landscape utilizing phytoremediation technologies as a slow but cost-effective clean-up process.