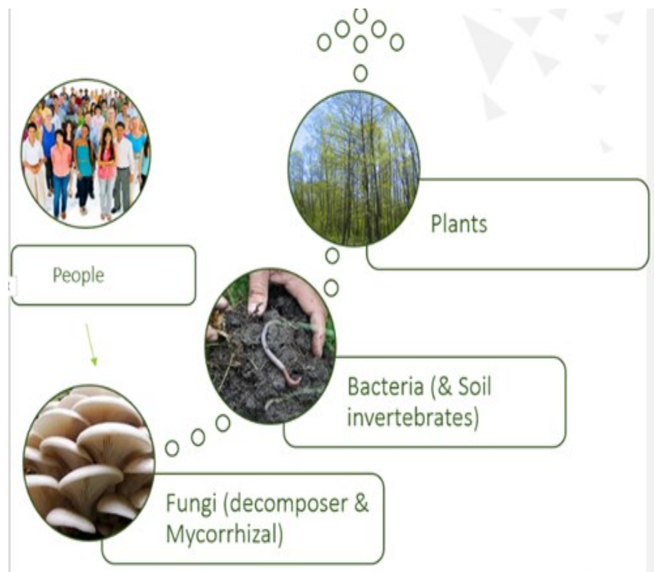
Bioremediation for Urban Gardeners #19

Healing City Soils is a partnership between the Compost Education Centre and Royal Roads University, which provides gardeners with information about soil health and offers free heavy metal soil testing. Healing City Soils also offers education and workshops to help our community better understand, manage, and build healthy soil for resilient gardens. This project began in 2016 and will continue with free soil testing made available each spring in the years to come. To find out more, visit: www.compost.bc.ca/healing-city-

Bioremediation for Urban Gardeners is intended to build off of Factsheets #11 & #12 which offer a starting place for understanding soil contamination and best practices for growing food in soils that may contain heavy metals. This Factsheet (#19) offers ways that home-scale food gardeners, small urban farmers and community gardeners can draw on their soil and plant knowledge and skills to remediate soils that are contaminated with low to moderate soil concentrations of heavy metals. We offer some ideas for how to employ natural methods to remediate soils by working with plants, fungi and/or bacteria. These strategies are all under the umbrella of '**bioremediation**.' The focus of this factsheet is on one type of bioremediation– **phytoremediation**– which involves growing plants to extract and reduce heavy metal concentrations in the soil over several seasons. This approach may not be suitable for all sites, including large and highly contaminated sites, nor sites with types of contaminants other than heavy metals, such as organic contaminants including PCBs, legacy pesticides, or petroleum products.



What is bioremediation?

'***Bioremediation***' involves working with living organisms to address harmful substances in the soil and water. This approach amplifies the natural abilities that plants, bacteria and fungi have to break down, remove or bind up contaminants in or from soils. We say this approach 'amplifies' the abilities of living organisms because these processes already occur naturally, as fungi and bacteria use organic materials (mostly carbon) as a source of energy or materials to build and maintain their cellular structures, and as plants draw the elements they need from the soil. In other words, some plants remove metals from the soil and accumulate them into their biomass because they are like the minerals and nutrients they need to get from the soil for their growth and nutrition. Bacteria and fungi transform organic contaminants, such as petroleum products, because they have the same carbon-rich make-up as the organic matter that they eat. When bacteria and fungi consume contaminants, they break them down using acids and enzymes (similar to what happens in our stomachs). In doing so, they transform the contaminants into less toxic substances.

Bioremediation looks at the whole systems, including the living soil communities, and aims to restore optimal health conditions to people and communities. Life replenishes itself. Soil cleans itself. Leaning in to listen and lending our hands to this process allows us to open to this dynamic system much larger than us.

-Nancy Khlem (2016),
The Ground Rules

Various plants, fungi and bacteria have different natural abilities to deal with different kinds of contaminants- inorganic ones (such as metals) and organic ones (such as petroleum products). In practicing bioremediation, we aim to provide the right conditions for our plant, fungal, and bacterial allies to do what they do best! So we (engaged community members and food gardeners) are a vital part of bioremediation strategies. **In nature, organisms work together in concert and in succession. Holistic bioremediation efforts mimic nature in these ways to support the regeneration of landscape ecologies.**

These approaches are different than conventional remediation, which typically consists of digging up the contaminated soil, disposing of it at a contaminated waste facility, then replacing the soil– often at a great expense (known as ‘**dig and dump’**), or capping the contaminated soil with an impermeable barrier and adding clean soil on top. In contrast, using bioremediation strategies, we aim to address the toxicity and restore the health of the soil on site (‘**in-situ**’).

The right approach for your site *depends on the kind of contaminant.*

A soil contaminant is an element or chemical present in the soil at a concentration that poses health risks to plants, animals or humans. It is important to distinguish between organic and inorganic contaminants because we use different strategies and work with different organisms to address each. Plants are generally the right tool for heavy metals (inorganic), and bacteria and fungi are generally the right tools for organic contaminants.

Element — •aka 'heavy metal' or 'inorganic' contaminant (eg. lead, mercury)

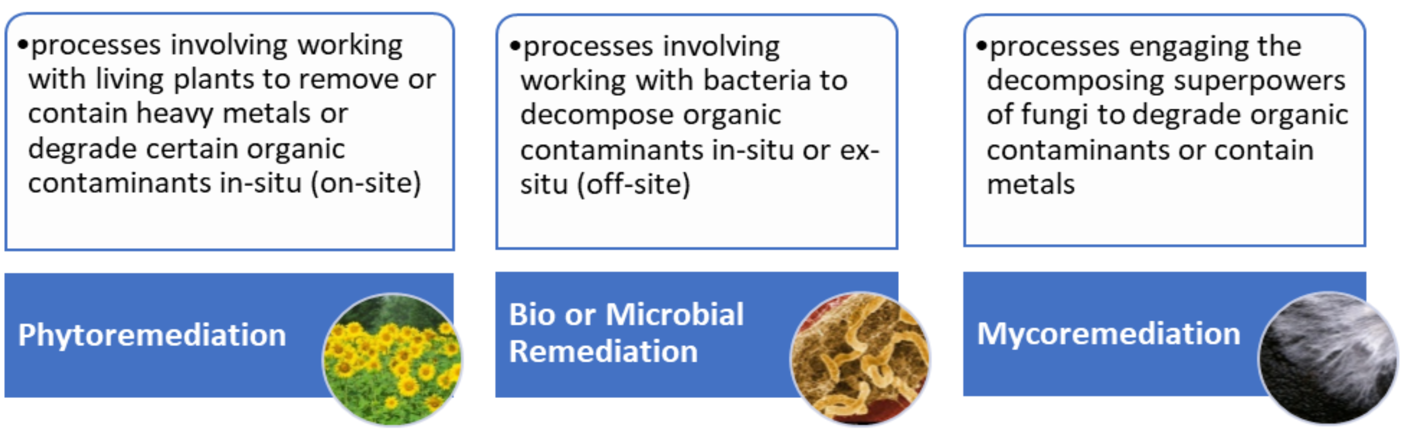
Chemical — •a carbon-based contaminant aka 'organic' contaminant (eg. diesel oil, PAH's)

You can read more about different kinds of soil contaminants and where they come from in *Factsheet #12: Soil Contamination*. The key thing to know for bioremediation is:

Organic contaminants can be degraded and transformed from something toxic to something less toxic or non-toxic through the metabolism of various organisms–especially bacteria and fungi, but also worms and trees. For example, poplars can degrade PAHs through their roots, and worms speed up hydrocarbon breakdown.

Unlike organic contaminants, **heavy metals** cannot be broken down or degraded, so they keep building up and accumulating in soils. However, the characteristics of heavy metals may change so that they are more easily taken up by plants or animals (known as ‘**bioavailability**’) and are more mobile in the soil. As a result, they can be concentrated in plants and extracted.

Types of Bioremediation:

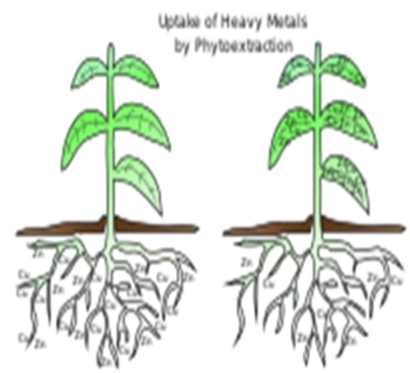


Fungi and bacteria degrade organic contaminants.

Some decomposer fungi that degrade organic matter for their food, such as *Pleurotus ostreatus* (Oyster mushroom), show promise in being able to degrade complex organic contaminants like diesel oil, PAHs and other contaminants. Lab and bench-scale studies have found Oyster mushroom is able to break down the PAHs in diesel oil and cigarette butts, and key components of the plastic in diapers. These applications need to consider the basic needs of fungi- moisture, air, and some easier-to-digest food. High ratios of mycelium also need to be applied to the contaminated substrate (whether its diesel-contaminated soil, cigarette butts, diapers or others). To work with fungi and bacteria for remediation, you need to employ **mushroom cultivation, thermophilic** and **aerobic composting procedures**. So if you want to explore myco- and bioremediation, learning those skills is a good place to start!

You are going to need large amounts of **spawn** (pre-grown mycelium) and/or **compost** or **compost tea**. Bioremediation efforts typically involve layering the spawn with the contaminated soil (or other contaminated material) and making sure it stays moist while the mycelium goes to work on it. For hydrocarbon-based contaminants, such as most petroleum products, decomposer fungi like Oyster mushroom can degrade much of the contaminants in 3 weeks to 3 months, depending on the mass of the contaminated area, the level of contamination, and other factors. This first decomposition with fungi has been shown to be more effective when followed up with composting. **In fact, proper hot composting of soil corrupted by organic contaminants, and application of compost tea and hot compost, is a simple and effective way to address organic contaminants and repair toxic soil.** For more information on how to make awesome compost, see prior factsheets by the Compost Education Centre or attend any of our free composting workshops. You can read more about myco- and bioremediation in some of the resources listed at the end of this factsheet. **However, more research is needed so that protocols for community-scale myco- and bioremediation can be applied safely and effectively to repair contaminated soils.**

It is important to consider that soils contaminated with organic chemicals may also have heavy metals present that will not be removed through myco- or bacterial remediation strategies. Fungi are known to interact with metals in different ways: some bind them in their mycelium (their underground network), others concentrate them in their fruiting bodies (aka the mushroom). For example, Shaggy Mane mushroom (*Coprinus comatus*), a decomposer fungus pictured to the left, is a hyper-accumulator of mercury, cadmium and arsenic. Also, the plant-root-associated Arbuscular Mycorrhizal Fungi have been known to enhance the hyper-accumulation of heavy metals in their plant partner. This practical understanding would aid phytoextraction strategies. The same Arbuscular Mycorrhizal Fungi (and other fungi) have conversely been found to have the opposite effect– to bind metals in the rhizosphere (root zone)– and keep them from being taken up by their plant partner. This is desirable in food gardens and farms where we don't want metals in our crops! More research is needed to clarify what controls binding metals in the rhizosphere so that this strategy can be applied by farmers and phytoremediators. Arbuscular Mycorrhizal Fungi and contamination research, led by soil toxicologist Danielle Stevenson is being supported through Healing City Soils partnerships (*see DIY Fungi for more info*).



Plants concentrate and extract heavy metals.

For heavy metal contaminated soil, living plants are the best tools for bioremediation. The term ***phytoremediation*** describes a group of processes working with living plants that provide for in-situ (on-site) clean up through:

- Removal - ***phytoextraction (****or* ***phytoaccumulation)***
- ◊ Degradation - ***phytodegradation (****or* ***rhizodegradation***)
- ∗ Containment -***phytostabilization***

Phytoextraction is the most suitable option for small-scale veggie gardeners to reduce low to moderate concentrations of heavy metals in their home garden soils. Through phytoextraction, plants take up contaminant metals with their roots and move them to accumulate them in large quantities within their stems and leaves (EPA, 2001). Certain plants called **"hyper-accumulators"** can accumulate unusually large amounts of metals compared to other plants. These plants can be planted or seeded and allowed to grow for several weeks or months, accumulating metals in their aboveground parts, before being harvested and disposed of. This can be repeated as necessary to bring soil metal levels down to below the ***acceptable limits*** for agriculture. These limits are guidelines for soil metal concentrations set by the Canadian Council of Ministers of the Environment to decrease the risk to human health. Our phytoextraction goal would be to reduce soil metal concentrations to below the acceptable limits and avoid health impacts. You can read more about these soil metal guidelines in Fact Sheet #12.

Phytoextraction is accessible to small-scale farmers and gardeners because it doesn't require sophisticated equipment, and it uses many of the same tools and skills that they already have. It doesn't require digging up and replacing the soil, and the amount of plant matter that is disposed of is much less than the amount of soil disposed of in conventional remediation. For more information regarding the disposal of plants after phytoremediation, see below. This approach to removing soil contaminants is low-cost (as compared to conventional approaches), solar-powered, and is known to be effective. For the extraction of heavy metals from soil, cost savings have been estimated at around $5 per 20/sq.ft. compared to conventional methods.

In some cases, phytoremediation can permanently eliminate most or all of the pollutants from a site, instead of transporting them to a landfill. One of the most effective hyper-accumulators for the remediation of multiple heavy metals is Alpine Pennycress (*Thlaspi caerulescens,* pictured left), which is in the Brassica family and can accumulate four heavy metals in huge concentrations - 52,000 ppm of Zinc, 16 200 ppm of Nickel, 15 000 ppm of Cadmium and 2 740 ppm of Lead (Awere et al., 2014).

This Photo by Unknown Au-

Is Phytoextraction right for you and your site?

It is important to note that phytoremediation is **site specific**; not all plants are capable of removing all pollutants and not all sites are well suited for phytoremediation. The BC Ministry of Environment classifies levels of contamination by the concentration of pollutants, and whether or not they are within the range of rehabilitation. Soil testing will determine what level of contamination is present at a site. You can pay for your soil to be tested at local labs (such as those listed in the Soil Contamination factsheet), or apply to access free soil heavy metal testing through Healing City Soils each spring.

One of the most important considerations about using phytoremediation is time– *phytoextraction is slow*. Depending on the concentrations of metals in your soil, it can take several planting cycles over multiple growing seasons to reduce the metals in your soil to acceptable limits. It involves the labor of setup and then maintenance and monitoring. Phytoremediation requires commitment and time, and your site will not be producing edible crops. Further, it can only address metals at shallow depths accessible by the root systems of the plants you are using. Roots of various plant species can reach a depth of 0.3 m to 5 m.

*There is a useful decision tree for determining whether Phytoextraction is a good option for you and your site. This diagram is shown at the end of this document.

Planning and Implementation

Considerations to keep in mind when creating a phytoextraction plan:

- type and amount of metals present
- size and depth of the polluted area
- type of soil and conditions present
- irrigation and access to water
- identification of safety and access issues
- development of signage (if it is a boulevard or community garden)
- time and labor required to implement and maintain plan

Maintenance

Maintenance requirements should be considered when selecting plant species, including:

- the frequency with which the plant must be mowed/harvested/replanted
- the need for soil amendments such as fertilizer
- the need for replanting, pruning, harvesting, and monitoring
- soil testing & plant testing to follow progress

Dismantling

The dismantling stage is marked by the harvest and removal of the plant biomass, i.e. the whole plant including the roots. *What should you do with the contaminated plant matter?*

There are a few options for what to do with the contaminated plant matter.

1) Test the plant matter for metals. At the end of a remediation project, and at stages throughout, you will want to test the soil and plants to determine if the metals are being reduced in the soil through going into the plants. This will help you see whether the extraction is working; and also give you a better sense of how to dispose of your remediation plant matter.

MB Labs in Sidney (info@mblabs.com and 250-656-1334) offers leaf testing services for metals for around $147/sample. One sample is 8 leaves brought in a bag for analysis.

Plant and yard waste is banned from Hartland landfill in Saanich, **but you also would not want to add metal-laden plants into your compost and yard waste bins because doing so may spread the metals further into our food system.** To determine whether you need to dispose of the plant matter as hazardous waste, you will need to have the lab use a TCLP method. This is to ensure that your harvested plants don't run the risk of leaching contaminants back into the ground and further into the groundwater once they're disposed of. If the test is positive, they have to be disposed of at a hazardous waste landfill in a container. This is not very likely, but be prepared to bear the costs of it ($30-70/garbage bin). The silver lining: if hazardous waste disposal is required, your remediation has been very successful!

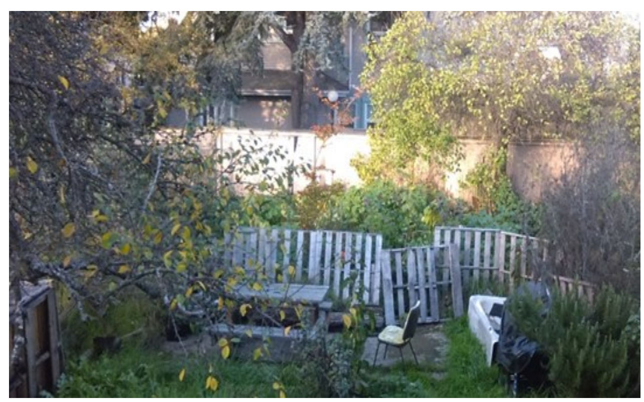
2) Reduce the volume of the plant matter through composting or incineration. Since you will likely be doing multiple rounds of planting and harvesting the metal-containing plants, you may want to reduce the volume of the plant biomass on site so that you have a smaller volume of hazardous material to dispose of off-site, and a smaller amount to contain and steward on your site. There are a few ways to do this:

a) *Compost it in closed containers* (e.g. in garbage cans with lids and no holes). There, the biomass will anaerobically compost down into a sludge of a much-reduced volume. It is important to not leave the plant matter you used in remediation efforts on-site nor add into your regular compost because it will leach contaminants back into the soil.

b) *Incinerate it* and then bring the ash to a hazardous waste disposal facility. If plants are incinerated, the volume of ash will be less than 10% of the volume that would be created if the contaminated soil itself were dug up for treatment (EPA, 2001). Wear a particulate mask during incineration to prevent metals from the ash getting into your lungs.

Safety Considerations

Some of the plants you may use in your phytoremediation effort have traditional medicinal uses, so if your site is a community garden, boulevard garden or otherwise publicly accessible, be sure to create signage warning of the hazards of ingestion. Although they do not pose risks when growing at the site, or even during handling, the plants should not be eaten. It's best to use non-edible plants for remediation and visible signage to discourage members of the community from eating these plants. If you have pets, children, or your site is visited by other animals, consider installing some temporary fencing for the duration of the project so that the potentially toxic plants are not ingested. In the picture to the right, a make-shift fence has been installed around a remediation area using recycled pallets.



*Avoid exposure to heavy metals while working on remediating the soil: lead and other toxic metals are commonly found in the dust and soil themselves, so wear gloves, boots, and 'remediation' clothes that you change out of before entering your house. Wearing a particulate mask is a good idea while you are actively digging or working in the soil.

*****Investigate the source of the contaminant, and consider whether it's being continuously deposited via emissions, dust, air pollution, or another source. You will want to continue to test the soil to ensure that metals are not being re-deposited, and follow best practices for reducing your exposure when gardening.

Phytoextraction Steps and Timeline:

1) Prepare the soil. The first step is preparing the soil in the entire area that you are aiming to remove metals in, so that only bare soil remains and is ready to be seeded with your phyto-extractor plants. This could involve removing existing plant matter completely and/or 'double-digging' (basically digging and flipping the grass and/or soil). Adding compost and/or compost tea to build the soil and invite beneficial microbes is also a great idea, as these additions will support your phyto-extractor plants. This is the same thing you would do to prepare a garden bed for seeding or planting.

2) Install fencing or a protective barrier and set up irrigation if necessary.

3) Select plants and get seeds or seedlings. Generally, plants that grow quickly, have extensive root systems and produce a lot of above-ground biomass are good candidates for remediation. When selecting plants for a remediation project, take care to not introduce invasive species in areas where those species would have the tendency to hinder growth of native plants. Some plants have been studied to be effective at concentrating metals and these are listed below. **The native plants listed below are specifically native to the ecologies of southern Vancouver Island.** Some native plants have not been studied as extensively for their potential as remediators, but Ecological Restoration Technicians suggest that generally, if you find a plant in the same genus or family as a known remediator, you would probably get a similar result, like an analog. So, if Indian Mustard is a known remediator, then a reasonable assumption is that another Brassicas like the native Field Mustard should be good as well. In terms of a sunflower, for Southern Vancouver Island we could try native asters such as Beggar Ticks or Sneezeweed (University of Victoria, Ecological Restoration Program, personal communication).

Soil pH and metal extractability
Soil pH affects how 'mobile' or 'soluble' metals are– how bound they are in the soil and thus how easily they can be extracted by plants. Generally, at a neutral soil pH (between 6.5-7.5), many metals are less extractable by plants. In acidic soils (with lower pH), metals tend to be more soluble and more easily taken up by plants– this is true for lead, cadmium, zinc and aluminum. Arsenic is the opposite– more 'mobile' in more basic soils and more 'bound' in acidic soils. Depending on which combination of metals you are dealing with, you may want to lower the pH of your soil to make the metals more easily extractable by the plants. You can monitor soil pH with a pH meter purchasable at any garden supply store; and modify pH with elemental sulfur, ammonium (NH_4)-based fertilizers, or lots of coffee grounds.

Phytoextractor Plant List, by metal:

Metal	Plant (Common Name and *Latin Name*)
Aluminum (Al)	**Native**: Western Goldenrod (*Euthamia occidentalis*) – Perennial **Non-native**: Hairy Goldenrod (*Solidago hispida)* – Perennial; French Hydrangea (*Hydrangea machrophylla)* – Perennial
Arsenic (As)	**Native:** White Lupine *(Lupinus albus)* – Annual; Spikerush (*Eleocharis acicularis)* – Annual/perennial; Native Ferns less studied but potential arsenic extractors – Perennial **Non-native**: Chinese Brake Fern *(Pteris cretica)* and others: *Pteris biaurita*, *P. quadriaurita, P. ryukyuensis* – Perennial
Cadmium (Cd)	**Native:** Yarrow (*Achillea millefolium)* – Perennial; Willow (*Salix sp* such as native Pacific Willow (less studied than non-native remediator *Salix negra)* – Perennial **Non-native**: Indian Mustard (*Brassica juncea)* – Annual; Sunflower *(Helianthus annuus)* – Annual; Alfalfa (*Medicago sativa)* – Annual; Alpine Pennycress (*Thlaspi caerulescens*) – Annual; Mugwort (*Artemesia vulgaris)* – Perennial; Common Foxglove (*Digitalis purpurea)* – Biannual; Chickory (*Cichorium intybus var. foliosum)* – Perennial; Mouse-ear/Field Chickweed *(Cerastium arvense)* – Annual
Chromium (Cr)	**Native:** Willow (*Salix sp* such as native Pacific Willow (less studied than non-native remediator *Salix negra)* – Perennial; Balsam ragwort (*Senecio pauperculus)* – Perennial **Non-native**: Indian Mustard (*Brassica juncea)* – Annual; Sunflower *(Helianthus annuus)* – Annual; Alpine Pennycress (*Thlaspi caerulescens*) – Annual

Metal	Plant (Common Name and *Latin Name*)
Copper (Cu)	**Native:** Willow (*Salix sp* such as native Pacific Willow (less studied than non-native remediator *Salix negra)* – Perennial; Small fescue (*Vulpia microstachys)* – Annual **Non-native**: Indian Mustard (*Brassica juncea)* – Annual; Sunflower *(Helianthus annuus)* – Annual; Alpine Pennycress (*Thlaspi caerulescens*) – Annual; Mugwort (*Artemesia vulgaris)* – Perennial
Mercury (Hg)	**Native:** Willow (*Salix sp* such as native Pacific Willow (less studied than non-native remediator *Salix negra)* – Perennial **Non-native**: Sunflower *(Helianthus annuus)* – Annual
Nickel (Ni)	**Non-native**: Indian Mustard (*Brassica juncea)* – Annual; Sunflower *(Helianthus annuus)* – Annual; Alpine Pennycress (*Thlaspi caerulescens*) – Annual; Mugwort (*Artemesia vulgaris)* – Perennial; Wheat (*Triticum aestivum)* – Annual
Lead (Pb)	**Native:** Vancouver Island Beggarticks (*Bidens amplissima*), Field Mustard (*Brassica rapa*); Willow (*Salix sp* such as native Pacific Willow (less studied than non-native remediator *Salix negra)* – Perennial **Non-native**: Indian Mustard (*Brassica juncea)* – Annual; Sunflower *(Helianthus annuus)* – Annual; Alpine Pennycress (*Thlaspi caerulescens*) – Annual; Blue Sheep Fescue (*Festuca ovina)* – Perennial; Red Mulberry (*Morus rubra)* – Perennial; Garden Sorrel (*Rumex acetosa)* – Perennial; Mugwort (*Artemesia vulgaris)* Perennial; Wheat (*Triticum aestivum)* – Annual; Alfalfa (*Medicago sativa)* – Annual;
Zinc (Zn)	**Native:** Moss Campion (*Silene acaulis*) – Perennial; Willow (*Salix sp* such as native Pacific Willow (less studied than non-native remediator *Salix negra)* – Perennial; Spikerush (*Eleocharis acicularis)* – Annual/perennial **Non-native**: Indian Mustard (*Brassica juncea)* – Annual; Alpine Pennycress (*Thlaspi caerulescens*) – Annual; Sunflower *(Helianthus annuus)* – Annual; Garden Sorrel (*Rumex acetosa)* – Perennial; Bladder campion (*Silene vulgaris*) Tomato (*Solanum lycopersicum*)
PAH's (degraders)	**Native:** White Clover (*Trifolium repens)* – Perennial; Hybrid Poplar (*Populus deltoides x P. nigra)* – Perennial **Non-native**: Sunflower *(Helianthus annuus)* – Annual; Red Mulberry (*Morus rubra)* – Perennial
Total Petroleum Hydrocarbons	**Non-native**: Red Clover (*Trifolium pretense)* – Perennial

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.

4) Maintain and monitor your site like you would any other garden. Regular water is important, and you may want to give your plants a boost occasionally with an organic fertilizer such as compost tea or compost.

5) Harvest and dispose of plants. 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 have 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.

6) At the end of the growing season, re-test the soil (and test the plants too!) 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 growing seasons.

Phytoextraction Case Study: Backyard Regeneration Project, Fernwood, Victoria B.C.
This phytoremediation project took place in a 1/8 acre Fernwood-area backyard where the inhabitants wanted to grow food but tested the soil and found it had 310 ppm Lead, 260 ppm Zinc, 59 ppm Chromium and very high levels of Aluminum as well as Mercury, Cadmium, Nickel and Copper that needed to be addressed before growing food. A group of community members and students participated in a year-long project to remediate the site. We built a pallet fence around the site to keep dogs and pets out, then started preparing the soil by double digging and making big piles of hot compost. The compost was added to the soil as well as aerobic compost tea and huge amounts of coffee grounds. A raised bed garden was built in the front yard so the inhabitants could grow food while the remediation process was taking place in the back. We first needed to address the aluminum so that our remediator plants could grow (aluminum is toxic to many plants at such high concentrations). We planted fava beans and barley to extract the aluminum, letting them grow from spring to early summer. After harvesting them and placing them in sealed containers to anaerobically compost, we seeded white clover, wooly sunflower and yarrow– native plants that are analogs to known phytoextractors for the metals we had on site. After one season, many 'volunteer' remediators also showed up on site including mallow and milk thistle. We harvested all the plant matter and added it to the bins where it reduced to a small amount of sludge. We re-tested the soil through the Healing City Soils project and found that all of the metals had been reduced to below acceptable limits– soil lead levels were reduced to 131 ppm, Zinc to 150, Chromium to 20 and Hg, Cd, Ni reduced by about half. Copper was the only metal whose soil concentration was unaltered.

You can gain ideas and inspiration from 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/.

Terminology

Binding: also known as 'locking up' or 'immobilizing' – means that the metal(s) are attached and chemically held in the soil; this means they are immobile and unlikely to be taken up by plants or leached out through the movement of water.

Degradation: the act or process of breaking down a molecule into smaller parts. Another word for 'breaking down.'

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. E.g. Decomposer fungi excrete enzymes into organic matter to break it down so they can extract the carbs, sugars, and other nutrition they need from it.

Extraction: the removal of a substance from a substrate by chemical or mechanical action.

In-situ: methods in which the contaminated material is treated on-site, whereas when the material is physically removed to be treated elsewhere it is referred to as *ex-situ.*

Hyper-accumulator: a plant capable of growing in soils with very high concentrations of metals and absorbing these metals through their roots, then translocating the metals into their aboveground parts and concentrating extremely high levels of metals in their tissues.

Solubility: how likely and to what extent a contaminant will dissolve in water.

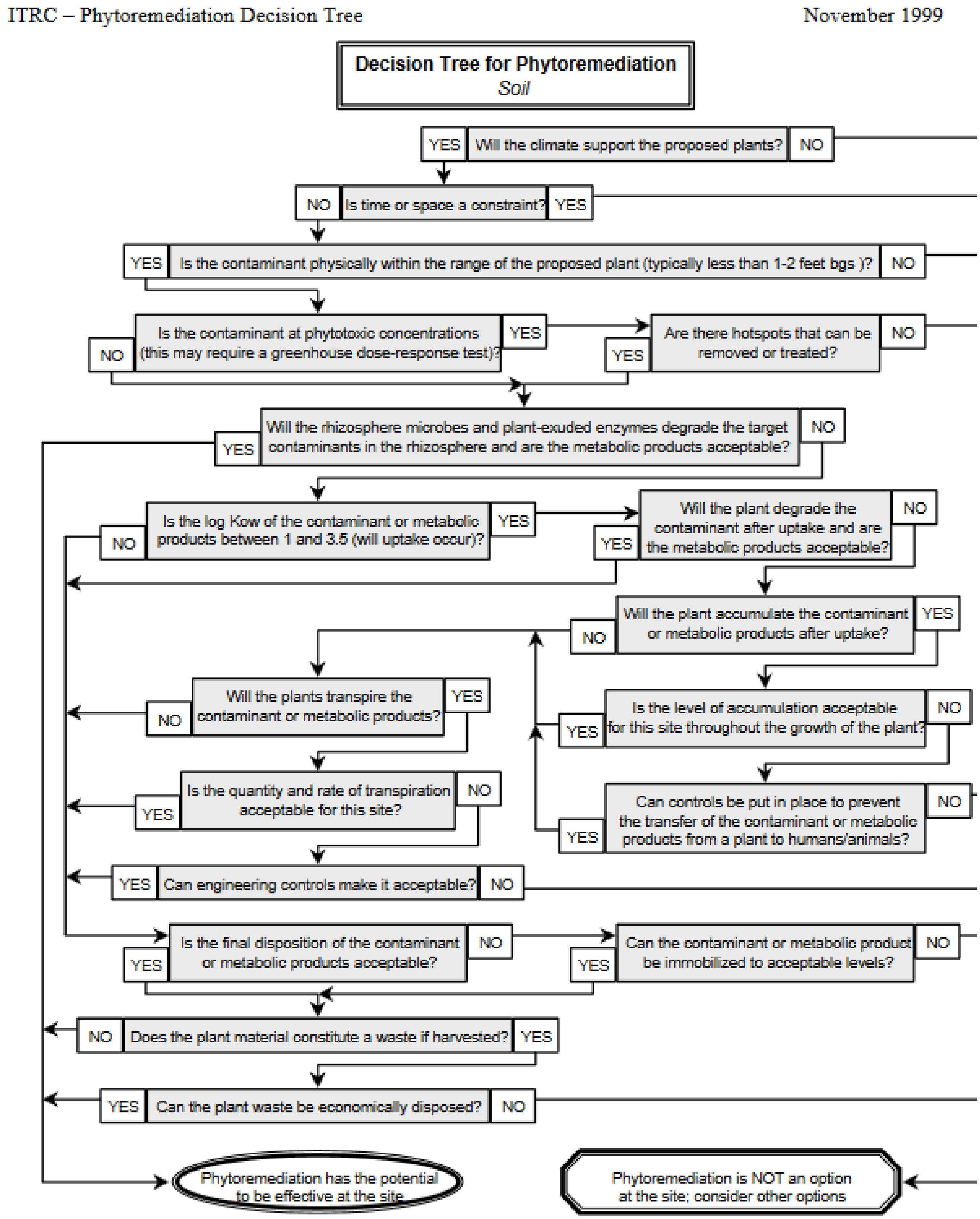
Mobility: how mobile/moveable a contaminant is in the soil…. Will it move when water flows through, will it move into roots and up into plants?

pH - a measure of the concentration of hydrogen ions in the soil solution. Soil acidity is expressed as soil pH, using a scale from 0 to 14. Soil pH values below 7 indicate acidic soil, and values above 7 indicate basic (alkaline) soil. As the hydrogen ion concentration and acidity increase, soil pH decreases.

Rhizosphere: the region of soil in the vicinity of plant roots in which the chemistry and microbiology is influenced by their growth, respiration, and nutrient exchange.

Decision tree to determine if Phytoremediation is a good option for you and your site.

This diagram was accessed in the Appendix of a student publication from UBC (2008): "From the Ground-Up - Greening Urban Brownfields in our Communities (A Toolkit for Municipal Government.)" shown below:



References and Further Reading:

Scientific Articles- available through Google Scholar:

- Awere, E. et al. 2014. *Review of Effective Plants to Remove Multiple Heavy Metals from Contaminated Soils. Applied Phytotechnology in Environmental Sanitation, 3 (4): 131-136.*
- McIntyre, T. (2003). Phytoremediation of heavy metals from soils. Adv. Biochem. Eng. Biotechnol., 78: 97–123.
- Padmavathiamma, Prabha K. and Li, Loretta Y. (2007). Phytoremediation Technology: Hyper-Accumulation Metals in Plants. Soil, Air and Water Pollution: International Journal of Environmental Pollution.

Phytoremediation Guides and Resources:

- "Brownfields to Greenfields: A Field Guide to Phytoremediation." (2011) Published by youarethecity: www.youarethecity.com. Read more at: http://newyork.thecityatlas.org/lab/brownfield-remediation/lab-results-for-2011/
- "From the Ground-Up - Greening Urban Brownfields in our Communities (A Toolkit for Municipal Government.)" (2008) Published by Holmes, E, et al. UBC. Available through personal communication.
- US Environmental Protection Agency. (2001). *Brownfields Technology Primer: Selecting and Using Phytoremediation for Site Cleanup*. Washington D.C.
- BC Ministry of the Environment – Contaminated Sites Clean up resources. Available here: https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites/the-remediation-process

Books about Bioremediation:

- Earth Repair: A Grassroots Guide to Healing Toxic and Damaged Landscapes (2013) by Leila Darwish. See https://www.newsociety.com/Books/E/Earth-Repair
- "The Ground Rules Manual" (2016) and new book "The Soil Keepers" (2019) by Nance Khlem.
- See http://socialecologies.net/
- Organic Mushroom Farming and Mycoremediation (2014), Tradd Cotter.
- Radical Mycology (2016), Peter McCoy.

Other Online Resources about Soil Contamination and Bioremediation:

DIY Fungi- http://diyfungi.blog
Public Lab- https://publiclab.org/wiki/soil

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