DELFT UNIVERSITY OF TECHNOLOGY
MSC ARCHITECTURE, URBANISM AND BUILDING SCIENCES
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CLEAN CORRIDORS

A DATA-DRIVEN APPROACH FOR MULTI-SCALE GREEN INFRASTRUCTURE DESIGN

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Clean Corridors
A Data Driven Spatial Design Approach for Multi-Scale Green Infrastructure Design

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ABSTRACT

Global trends in urbanization, industrialization, and intensive agriculture are harming our (local) environment. These activities require significant amounts of resources, energy, and transportation, whilst creating increased waste streams. Poor management of these sites has led to severe soil, water, and air contamination. Currently, Europe has 2.8 million potentially soil-contaminated sites, with around 340,000 in direct need of remediation. Additionally, these activities cause land cover changes, shrinking and fragmenting the natural landscape. The decreased ecosystem connectivity is harmful to ecological processes and biodiversity.

Phytoremediation and green infrastructure (GI) planning offer robust nature-based solutions to these problems. Integrating these solutions holds the potential to utilize the same vegetation for both solutions. However, integration of these solutions is challenging due to the scalar gap between the locality of phytotechnologies and the regional scale that is used for GI planning.

This thesis presents a systematic approach to integrating small-scale phytoremediation interventions within regional-scale GI planning. Using a multi-scalar, data-driven framework, this research uses computational simulations, calculations, and assessments to identify optimal design solutions, including traditional GIS mapping, graph-theoretic networks, and neural networks. This integrated approach aims to enhance environmental remediation and ecosystem connectivity and provides a comprehensive strategy for sustainable regional planning.


Own image

GLOSSARY

Clustering – A statistical method that groups a set of data points in clusters, based on similarities in their data. Used for categorizing and segmenting large datasets.

CNN/ Convolutional Neural Network - A form of deep machine learning algorithms for processing structured grid data, like images and video. Often used in image classification and object recognition.

Contamination –The presence of potentially harmful or toxic substances in the environment, threatening human health and natural resources. Contamination is often the result of industrial, agricultural, or other anthropogenic activities.

Ecological Core – A critical habitat zone within a landscape that maintains high ecological integrity and biodiversity. Conditions differ from habitat edges and green corridors.

ERS/ Ecological Resistance Surface - A spatial visualization of how part of a landscape hinders or allows wildlife movement and ecological processes to take place.

ES/Ecosystem Services – The benefits that humans derive from natural ecosystems, including provisioning, regulating, supporting, and cultural services. ES are essential for sustaining (human) life.

GI/ Green Infrastructure – A strategically planned network of natural and semi-natural areas designed to deliver a wide range of ecosystem services, such as water purification, air quality improvement, and climate resilience.

Landscape Connectivity - The degree to which individual habitat patches are reachable from one to another, facilitating the free movement of species and ecological processes. Landscape connectivity is essential for biodiversity and resilient ecosystems.

MSPA/Morphological Spatial Pattern Analysis - A quantitative method for analyzing and characterizing the spatial configuration and patterns of landscape elements. MSPA is useful for assessing landscape structures.

PC / Probability of Connectivity – A metric used to quantify the probability that different habitat patches are connected within a landscape. Used as an index for quantifying landscape connectivity.

Phytoremediation - A sustainable remediation technique that utilizes plants to absorb, accumulate, and detoxify contaminants from water, soil, or air.

Phytotechnologies - Sustainable nature-based technologies that utilize plants and their associated microorganisms to manage, mitigate, and minimize the impact of contaminants on their environment.

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PERSONAL PICTURE OF ME ENJOYING THE PIEMONTESE NATURE, 2023

MOTIVATION

This thesis project dives into urgent environmental issues and the importance of adopting sustainable lifestyles. Anthropogenic challenges, a mix of technological, social, and spatial complexities, form the basis of my exploration. By using a data-driven approach combined with design, I aim to contribute to ongoing discussions and make a tangible impact on these critical issues.

My fascination with the power of data has always driven me to unravel complex systems. This thesis is a prime example of how optimization and efficiency challenges play a crucial role within our designed landscapes. As I recognize the limitations of technology, I view it as a tool rather than an end in itself. Implementing technology in the right way is highly significant and valuable for our current and future challenges.

Beyond the optimization challenges and the creation of new data-driven methodologies, I am captivated by the idea of implementing nature-based solutions. Nature holds immense power, yet understanding and harnessing it correctly remain key challenges in current spatial planning and beyond. The contrast between technology and natural solutions is a concept that deeply resonates with me.

With this thesis I hope to find and discover synergies between seemingly opposing interests. I want to demonstrate that designing for natural systems doesn't mean neglecting human needs. By prioritizing nature in our designs, we can simultaneously create better environments for ourselves.

Through this thesis, I aspire to inspire designers, spatial planners, policy-makers, and the broader audience to rethink our relationship with nature. I hope to raise awareness about the services ecosystems provide and our impact on them. As I see it, redefining our connection with nature is crucial in addressing the environmental crises of today and tomorrow.

01

INTRODUCTION

INTRODUCTION

CONTAMINATION

THE CURRENT STATE OF CONTAMINATION

The past decades have shown intense trends of urbanization, intensive and mechanized agricultural practices, and global industrialization. These anthropogenic activities are actively polluting and contaminating soil, water, and air systems and threatening ecosystems, human health, and global resilience to climate change. Over the last 10 years, industrial production volumes have increased by more than 10% (Eurostat, 2023). This growth inherently leads to higher demand for raw materials, increased energy consumption, more transportation needs, greater waste generation during production, and increased waste on the consumer end. Eventually, this results in higher pollution and contamination rates.

The current state of the European soil is appalling, with over 60% of all soil being considered unhealthy (European Commission et al., 2020). Unsustainable land management, soil sealing, overexploitation, and contamination, combined with the impact of climate change and extreme weather events are further degrading and harming the European soils. Today, approximately 2.8 million sites are labeled as potentially contaminated, with 340,000 of them being in urgent need of remediation practices. This estimate is considered conservative, as monitoring and identifying contamination remains a major challenge (European Commission, 2023).

60% of the contaminated sites are a result of unsustainable practices in the production sector. This highlights the need for action in the remediation of these sites and the adoption of more sustainable practices in the industrial sector. A large proportion of these contaminated sites are Brownfields (also legacy sites), often abandoned with unknown ownership (Ana & Natalia, 2018). Over the last few years, EU member states have shown progress in addressing soil contamination in inventorying and investigating contaminated sites. Investigation and remediation of almost 150,000 sites over the past 15 years (European Commission, 2021).

Until 2021, generalized legislation, frameworks, and policies for addressing soil contamination were lacking on the EU level. However, individual member states are actively developing their own legislation and long-term goals for managing contaminated sites, highlighting a growing awareness of the challenges within regional and national political settings (Ana & Natalia, 2018). Recently, the EU presented its EU soil strategy for 2030, providing member states with guidelines, frameworks, and concrete steps towards protecting and restoring soils. This strategy presents the goals and vision for all ecosystems in the EU to become healthy and unharmful for humans in the year 2050, with intermediate goals and milestones in 2030 (European Commision, 2019).

CONTAMINATION OR POLLUTION?

The terms 'pollution' and 'contamination' are frequently used interchangeably. However, the exact definitions of these two terms vary slightly. Contamination is defined as the introduction of alien and potentially toxic substances into the environment. Pollution specifically refers to anthropogenically introduced substances that pose a harmful impact on the (local) environment and human health. Differentiating pollution from contamination can be difficult and in some cases requires chemical analyses and effect-based measures (Chapman, 2007). In short, contamination is a wider term, relating to more than anthropogenically introduced and/or not necessarily harmful substances. Throughout this report, the term contamination will be used, to include as many locations and sites as possible, while minimizing the need for a thorough investigation.

INDUSTRIAL ACTIVITIES NEAR VERCELLI, PIEMONTE

IMAGE: OWN IMAGE

DETECTING SOIL CONTAMINATION

Soil contamination is often difficult to detect. Of the 32 different main soil types found globally, the EU houses 24 of those, each with its own identity and characteristics(European Soil Bureau Network, 2005). This diversity in soil types and properties within the European territory, complicates the generalization of assessment procedures for soil contamination, as background levels, accumulation, storage, and remediation capacity, and the mobility of contaminants differ among these different soils. Besides the variety in soils and their characteristics, the wide variation in contaminants and their different bioavailability, persistence, and toxicity depending on their chemical properties further impede generalized assessment methods. Therefore, contamination has to be addressed on a site-by-site basis (Jones et al., 2005).

CONTAMINATION SOURCES

POINT SOURCE VERSUS NON-POINT SOURCE

Soil contamination can be categorized as either a point source or a non-point source. Point source contamination occurs when specific, localized activities introduce contaminants to the soil, i.e., the source can be identified as a singular activity in a single place. Such activities include intensive industrial operations, inadequate waste disposal, mining activities, military activities, or accidental or intentional releases of contaminants (European Environment Agency, 2014). Contamination as a result of pesticides and fertilizers in agricultural settings is also classified as point source contamination, particularly in areas where they are applied or managed improperly (Westfall et al., 2005).

Non-point source contamination refers to widespread contamination that is the result of multiple, often indistinguishable sources. In contrast with point source contamination, there is not a singular activity or location to be identified. Non-point source contamination can be the result of agricultural or urban run-off, carrying the contaminants found along the way, or atmospheric deposition where airborne pollutants from multiple sources can settle over wide areas.

INTERCONNECTION BETWEEN AIR, WATER, AND SOIL CONTAMINATION

Soil contamination cannot be addressed without considering its interrelationship with air and water contamination. These three media are vastly interconnected and most contaminants transition through multiple media in different phases. A common pathway for contaminant migration is through surface runoff to streams and into soils, eventually leaching into groundwater systems (Panno & Kelly, 2004), but other pathways are possible as well.

Airborne pollution eventually deposits onto soil or water surfaces, either by dry deposition or precipitation (like acid rain). The contaminant accumulates in the soil system and slowly leaches into the ground of surface water. Simultaneously, contaminated soil particles can become airborne as dust, especially in dry and windy conditions. In more wet cases, contaminants in the soil can run off into surface bodies like rivers, lakes, or oceans in case of precipitation or flooding, contaminating the aquatic environment (Pericherla et al., 2020).

INDUSTRIAL CONTAMINATION

More than 50% of all the contaminated sites are the results of the production sector (European Commission, 2021). Industrial processes, including mining and manufacturing, historically have been leading causes of soil contamination. Industrial areas typically have much higher concentrations of trace elements and organic contaminants, caused by intentional and unintentional releases from industrial processes directly into the environment, including soils, water bodies, or atmosphere (Kabir et al., 2012). Accidental spillage and incidents are other major sources of contamination. Historical long-term industrial contamination, and inadequate waste disposal all contribute to soil contamination. A lot of these former industrial sites are currently abandoned, complicating the responsibility for remediation activities (Ana & Natalia, 2018).

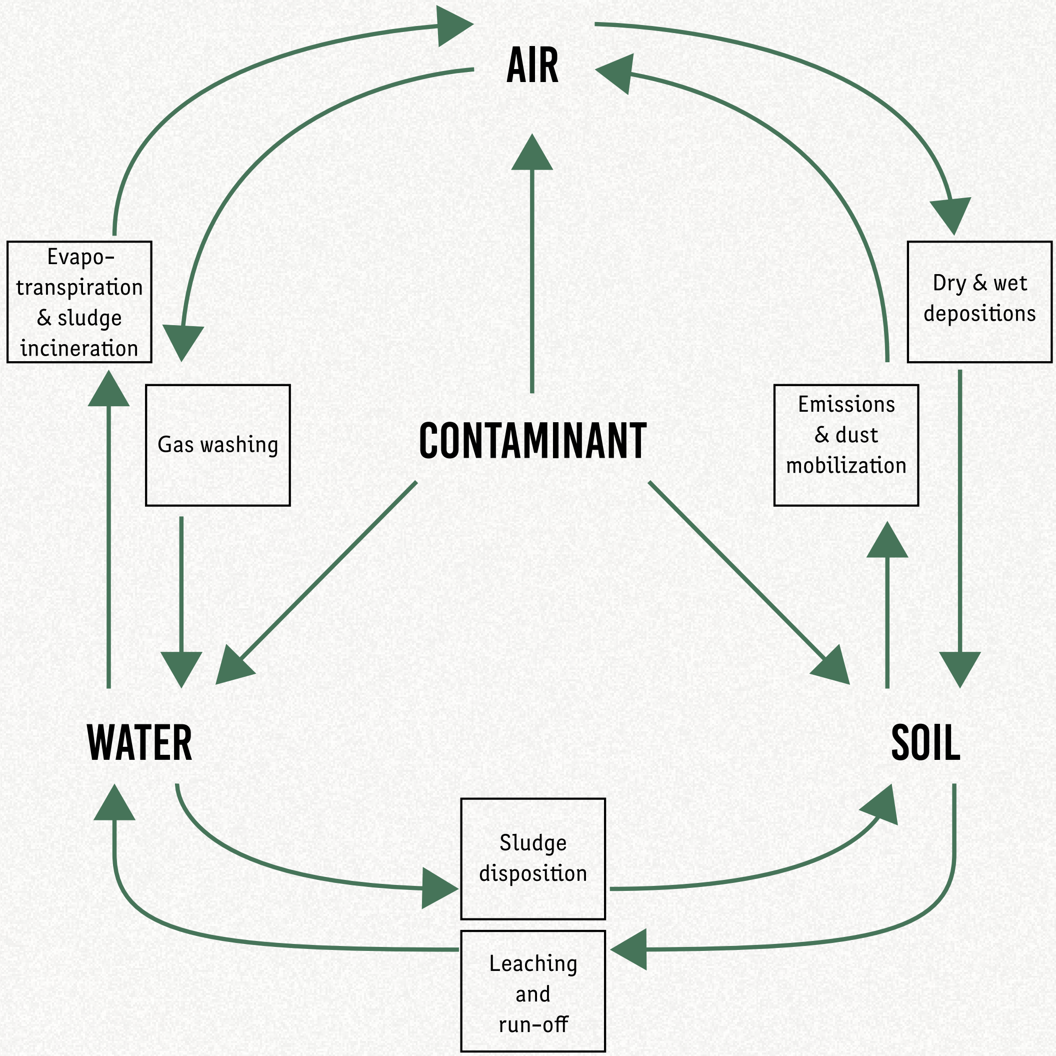


Figure: Interrelationship between air, water, and soil contamination adapted from Driving factors and challenges for EU industry and the role of R&D and innovation. IPTS, by Montalvo et al., 2007.

Production industries

Production industries are the source of a lot of soil contamination. The exact contaminants, concentration, and contamination pathways vary with the produced products, making it difficult to detect contamination and create generalized solutions to act upon it. Most contamination is the result of the accidental or intentional release of chemicals or trace elements into the direct environment, either as a part of the production process, waste management, or the use of chemicals that are integral to industrial activities. The following examples help to describe industrial contamination and its manifestations.

Plastics are widely used across all industrial sectors, mainly as containers or package material. Plastic waste has a substantial impact on environmental and public health. Although plastic only contributes to approximately 12% of the global amount of solid waste (Kaza et al., 2018), its chemical composition and persistent nature form a hazard to our environment. Most of the used additives in plastics, among others plasticizers, flame retardants, thermal stabilizers, and foaming agents are toxic to organisms (Bläsing & Amelung, 2018; Hahladakis et al., 2018). Despite many initiatives to increase recycling of plastics, still only 6% of the global plastics are reused (Ritchie et al., 2023). Plastic waste does not degrade entirely but gets fractured into smaller pieces. These micro- and nano-plastics end up in our food chains and threaten the health of plants, animals, and humans (Astner et al., 2019; Lwanga et al., 2017). The presence of trace elements further exacerbates the harmful potential of plastic waste to our (Velzeboer et al., 2014).

Textile manufacturing is another huge industrial source of soil contamination. Dyeing and finishing processes result in enormous volumes of wastewater, often containing trace elements and chemicals used in the process. Heavy metals, including arsenic, cobalt, copper, lead, mercury, and nickel are reported in these wastewater streams (Adeel et al., 2015; Bouatay et al., 2016). Spillage or release of this wastewater forms enormous threats to the direct surroundings but is also easily mobilized and spread over larger distances due to water streams and flooding.

Aluminum production is growing due to increased demand for lightweight products. The extraction and processing of aluminum results in high amounts of solid wastes and atmospheric emissions. Aluminum has an alkaline nature, potentially altering pH balances in soils. Besides that trace elements can leap into the ground during storage or processes, contaminating the soil with heavy metals. Red mud, a byproduct of aluminum production, contains elements of iron oxides, titanium, and fluorine compounds. Improper handling of this red mud can result in further soil contamination (FAO & UNEP, 2021).

Mining activities

Mining activities have been taking place over multiple millennia and have proven to be a major source of trace elements and contaminants. This is not only a result of mining operations itself, but mostly due to waste streams and emissions in the processing of the materials, including tailings, waste deposits, and smelting operations (Abraham & Susan, 2017a; Martín et al., 2014; Odumo et al., 2018). Many rocks are naturally rich in trace elements, which become mobilized during extraction processes (Abraham & Susan, 2017b; Middelburg et al., 1988). The use of chemicals generates chemically enriched waste streams, also post-mining activities at the site. Due to weathering, water, and wind erosion, tailing dams and rock waste deposits can continue to disperse the contaminants when no appropriate long-term maintenance is provided (FAO & UNEP, 2021).

Energy production

All the industrial processes described priorly are dependent on (large amounts of) energy and electricity. Currently, coal is the major energy source for electricity generation worldwide, producing approximately 36% of the total global electricity (IEA, 2024). Coal-based energy production results in large waste streams, including fly ash, bottom ash, boiler slag, and flue gases (Luther, 2010). The majority of this waste is collected and ends up in landfills, which often lack adequate measures for the storage and processing of these products, resulting in leaching and dissemination of the contaminants by erosion or weathering (Harkness et al., 2016; Yenilmez et al., 2011).

Petroleum products and crude oil cause major environmental concerns. Processing of crude oil and production of gasoline, diesel, lubricants, and other petroleum products are potential sources of soil contamination through point-source or diffuse pollution (Pinedo et al., 2013). Emissions during the use of these petroleum products in combustion engines lead to diffuse soil contamination due to atmospheric deposition, either dry or through precipitation. Accidental spillage, incidents, and managed releases into the environment lead to local soil contamination. Petroleum hydrocarbons prove to be the most common source of soil contamination throughout European contaminated sites, following an inventory by the European Environment Agency (EEA). Over 34% of all the reported contaminated sites are contaminated with some sort of petroleum, when considering other mineral oils, including polycyclic and volatile aromatic hydrocarbons (PAH, VAH respectively), hydrocarbon contaminants account for 53% of all the contaminated sites (European Commission, 2023).

Although emitting less during energy production and consumption, renewable energy production by PV panels is an important source of contamination. Solar electricity has gained popularity over the past decade and currently accounts for 6.7% of global electricity production (IEA, 2024). Construction of these panels is dependent on rare earth elements, including neodymium, indium, and tellurium, requiring extensive mining operations, emitting GHGs, and contributing to (local) soil contamination. Consecutively, the leaching of the modules containing these rare elements after breakage, accidents, faulty production, or products reaching end-of-life is another cause for concern. The amount of solid from PV panels is expected to increase from 8 million tons in 2030 to 78 million tons in 2050 (Chowdchury et al., 2020) further exacerbating the problems at hand.

Traffic and Transportation

Road and railroad traffic is a major source of releasing particulate matter, trace elements, salts, and PAHs (Kennen et al.,2015). Contamination occurs as the effect of tire wear, road abrasion, brake dust, oil leakages, (in)complete fuel combustions, and fuel additives, among others (Hjortenkrans et al., 2007). Vehicle emissions and road construction and abrasion result in excessive emissions of PAHs (Markiewicz et al., 2017), rubbers, plastic dust, and zinc (Councell et al., 2004; Davis et al., 2001; Hjortenkrans et al., 2007; Wik & Dave, 2009).

Railways are likewise polluting their direct surroundings with PAHs and trace elements including various heavy metals. Abrasion and friction between railroad tracks, pantographs, and train wheels result in the accumulation of heavy metals over time, especially since the contaminants are concentrated in such local brooksareas (Malawska & Wiołkomirski, 2001; Wiłkomirski et al., 2011). Although electric locomotives are considered environmentally friendly, they actively contribute to polluting their environment. Cleaning bays and railway sidings are often the scene for heightened concentrations of chromium, copper, iron, lead, mercury, and zinc (Fruhwirt et al., 2023; Malawska & Wiołkomirski, 2001). PAH-contaminants are often the result of leaking machine grease, hydraulic systems, fuels, and transformer oils, but wood treatment (and wear) of railway ties can be a source of PAH-mobilization (Moret et al., 2007; Thierfelder & Sandström, 2008).

Traffic pollution is considered an important portion of the contamination problem. Transportation infrastructure is found throughout the entire territory and pollution from the deposition of GHG can be found over large areas, sometimes large distances away from their actual source (Cornils, 2020). Another concern is food production in areas prone to this transportation pollution. Food production often occurs in landscapes and soils exposed to highway or railroad pollution, showing increased concentrations of harmful trace elements in plants and crops grown in the vicinity of highways (Modlingerová et al., 2012; Ogundele et al., 2015; Zechmeister et al., 2005). This increases the risk of contaminants entering the food chain and having adverse effects on human health (Kibblewhite, 2018).

MECHANIZED INTENSIVE AGRICULTURE
Food production aimed on maximizing crop yield by high inputs of technology, labor, capital, and chemicals, resulting in negative impacts on the (local) environment.

AGRICULTURAL CONTAMINATION

The agricultural sector is not only subjected but also a contributing factor to soil contamination. Soils within the agricultural landscape can be saturated with a variety of contaminants, both from point sources, like the application of fertilizers, pesticides, or herbicides, or from diffuse sources as atmospheric deposition or flooding. The main sources of soil contamination include pesticides, mineral or organic fertilizers, wastewater, and rural waste, each with its contaminants and challenges.

Pesticides

Pesticides are focused on repelling, controlling, or destroying pests that can be harmful to the crops it is applied to. There is a wide variety of pesticides available, including herbicides, insecticides, fungicides, rodenticides, nematicides, and many others. These pesticides can be applied either before or after harvest and aim to protect the crops from deterioration during growth, transport, or storage.

In most cases, pesticides are applied by spraying them onto the foliage of the crops (Dhananjayan et al., 2020). During spraying a lot of the pesticides are directly deposited onto the soil and leach into the soil and groundwater system. As a lot of pesticides are water-based, they wash during precipitation or overhead irrigation and run off into the soils. The use of granulates or spray to soil, directly contaminates the agricultural soil. Accidental releases, due to leaking pipes, spills, damaged storage, waste dumps, or incidents are other factors contributing to contamination (Kennen et al., 2015).

The accumulation of pesticides in soils or water systems is harmful to the natural environment as well as a huge risk to human health. When accumulated in the soil pesticides can kill beneficial soil micro- and macroorganisms that are essential for nutrient cycling and human health. Decreased soil biodiversity and species richness can be disruptive to the soil ecosystem and lead to decreased soil fertility and structure (Delgado-Baquerizo et al., 2017). Besides soil organisms, pesticides can affect other non-target organisms, including plants, insects, or other animals. The toxicity of the pesticides reduces biodiversity and can disrupt the natural balance of the affected ecosystem. Pesticides in agricultural soils are prone to mobilization by wind and weathering or floods and agricultural run-off. The mobilization of these pesticides results in large quantities of non-target species being affected over large areas. Continuous exposure to water and food processed with pesticides can result in chronic health issues, including cancer, reproductive problems, and developmental and neurological disorders, among others (Mostafalou & Abdollahi, 2013).

IMAGE: OWN IMAGE

Between 2000 and 2020, the global use of pesticides doubled, resulting in €52 billion in sales in 2019. The European market is one of the largest, contributing to 23% of global pesticide sales (Investigate Europe, 2022). The need for more sustainable farming practices and remediation of contaminated agricultural soils is evident.

Fertilizers

Mineral fertilizers are focused on adding nitrogen (N) and phosphorus (P) into the agricultural soils to accelerate plant growth and increase crop yields. Overuse of these fertilizers can lead to major environmental problems, including nutrient saturation in soil systems, drinking water pollution, and eutrophication of freshwater systems (Kulkarni & Goswami, 2019). Depending on the local circumstances microbial activities can transform nitrogen into nitrous oxide (N_2O), contributing to global warming and depletion of the ozone layer (Crutzen & Ehhalt, 1977). Nitrous compounds can contribute to soil acidification or acid rains when converted during soil and atmospheric processes. Ultimately, posing risks to human health and the environment. Eutrophication of water bodies promotes the excessive growth of algae, leading to oxygen depletion and the harming of aquatic organisms (Akinnawo, 2023).

Phosphorus fertilizers of inorganic or organic origin have become essential elements in current crop production systems (C.-W. Liu et al., 2014). The production of these phosphorus fertilizers is dependent on phosphate rock from sedimentary ores, which is a non-renewable source and therefore unsustainable. Mining and processing activities of these sedimentary ores lead to contamination of various heavy metal faotrace elements. These same trace elements can end up in the fertilizer itself and get accumulate in plant and soil systems during application (FAO & UNEP, 2021). Although the concentrations of these trace elements are minimal, they are cumulative and potentially harmful when not addressed properly (Jiao et al., 2012). Especially cadmium, copper, and zinc are often found in agricultural soils as a result of excessive fertilizer application. Although the amounts of these trace elements are minimal, they are cumulative and add up over time (Alloway, 1995; Andersson & Siman, 1991; Foy et al., 1978).

Organic fertilizer application can also contribute to soil contamination as a result of organic nitrogen mineralization and the presence of trace elements, PFAs, and other toxicities (Gottschall et al., 2017). The most common organic fertilizers in agricultural practices are compost, sewage sludge, animal manure, food (processing) waste, and municipal biosolids (FAO & UNEP, 2021). Positively, organic fertilizers slowly and gradually release their nutrients, preventing peak concentrations of nitrogen. Besides that organic fertilizers often enrich the organic carbon, improving soil health in general].

Organic fertilizers can be a source of antimicrobial (organisms), ending up in agricultural soils after application (Jiang et al., 2015). The antimicrobials are often applied in livestock farming for disease prevention and growth stimulation. However, the majority of these antimicrobials are not (completely) metabolized in human or animal systems (Marshall & Levy, 2011; Pistelli & Giorgi, 2012) and accumulate in manure, biosolids, and wastewater [(Bouki et al., 2013; Daghrir & Drogui, 2013)]. The introduction of these antimicrobials into the soil systems impacts the microbial populations within the soil and can lead to the dispersion of antimicrobial resistance in natural systems. The increased spreading of antimicrobial resistance is considered a huge risk for human health worldwide (Berendonk et al., 2015), challenging the treatment of bacterial infections, and viruses.

Excessive fertilizer application is a persisting challenge. Studies from the Food and Agriculture Organization of the United Nations (FAO) show an annual growth rate of 1.6 percent in global fertilizer applications. In 2019, 199 million tons of fertilizer has been applied worldwide (FAO & UNEP, 2021). The excessive use of fertilizers is caused by various factors. Firstly, there is little awareness and insufficient training on fertilizer use. Destructive effects of fertilizer application are often not directly visible or impact the farmer. A lack of accurate and detailed recommendations for fertilizer application, concentrations, and quantities is missing. Improved instructions and detailed recommendations could help reduce the over-use of fertilizers. Lastly, the costs of fertilizers are relatively low, especially when compared to the economic implications of decreased crop yields due to insufficient fertilizing. Excessive use is, from an economic perspective, less risky than applying insufficient amounts (FAO & UNEP, 2021; Westfall et al., 2005).

URBAN CONTAMINATION

Urban landscapes house a lot of potentially toxic chemicals and trace elements. Waste streams containing cleaning products, solvents, pharmaceuticals and personal care products, and other domestic waste get dispersed through the landscape and accumulate in the soils. Trace elements in the form of lead are considered the most dangerous, often found in old construction materials and paints. However, high concentrations of zinc and copper are often measured in urban areas as a result of dense traffic and atmospheric deposition from the transportation sector. Mercury, as a result of deposition after coal combustion, is another frequent contaminant in urban areas. Accidents and incidental leakages from fuel tanks, pipelines, sewage systems, and landfills carry various organic and inorganic pollutants. Power transmission equipment often contains PCBs, which can end up in the soil after incidents, abrasion, or deterioration (Ramírez-Camacho et al., 2017).

Urban waste streams often end up in municipal landfills. Over 70% of municipal solid waste ends up in landfills (Kaza et al., 2018), where the waste and contaminants accumulate and pose severe environmental risks. Poor design and management of landfills form the risk of leaching and atmospheric emissions(Renou et al., 2008). Especially the uncontrolled combination of various contaminants and the interaction between the individual components are potentially very harmful to human health and the environment (Barčić & Ivancic, 2010; Owusu Boadi & Kuitunen, 2002; Talyan et al., 2007). The lack of data and information in terms of specific contaminant types and concentrations further challenges these situations.

Besides the urban contribution to waste streams and the distribution of contaminants through urban activities, the lack of natural infiltration influences the spread of soil contamination in these areas. Impervious and sealed soils, including roads, sidewalks, and buildings, prevent water from infiltrating the soils. Precipitation and rainwater accumulate and carry pollutants and contamination during surface run-off, depositing this cumulative contamination in surface water or soils. Instead of being dispersed, the contaminants are now concentrated in one very local location. Furthermore, the run-off can lead to increased erosion and sedimenta-

LANDFILLS ARE A MAJOR SOURCE OF SOIL CONTAMINATION

IMAGE: ALAN LEVINE (2013). KING OF THE TRASH HILL. GATHERED FROM: HTTPS://WWW.FLICKR.COM/PHOTOS/COGDOG/

tion, mobilizing contaminants and degrading surrounding surface water and other soils. Furthermore, sealed surfaces impede the natural degradation of organic contaminants, as they limit soil exposure to air and microorganisms essential for biodegradation.

EFFECTS OF SOIL CONTAMINATION

HUMAN HEALTH EFFECTS

Soil contamination poses significant threats to human health. These effects can range from acute to chronic, dependent on the contaminant type, concentration, and time of exposure. Health effects are the result of human interaction with the soil, often via one of three main pathways:

1. Eating soil particles; mainly by younger children while playing outdoors or by improperly washing or handling food
2. Inhalation of small soil particles; contaminated soil particles can become mobilized by erosion or weathering.
3. Dermal absorption; skin contact with contaminated soils can result in the absorption of contaminants, especially when no safety or hygienic measures are taken,

A recent study by Levasseur et al. (2022) investigated the impacts of mining and industrial activities on households living in the vicinity of these sites. Three cases, in France, Portugal, and Spain, showed lower birth weights, increased risks of chronic diseases, increased premature mortality, and lowered health status among children. From a socio-economic perspective, the affected neighborhoods often are less educated, have lower average incomes, and have an increased demand for health services. A second study researched the impact of landfills on local populations all over the European territory. The 1,544 researched landfills are expected to have resulted in 61,325 disability-adjusted life years annually, as an effect of contamination and pollution from landfills (Shaddick et al., 2018).

Love Canal, NY

An infamous case of soil contamination affecting people's health and communities is the case of Love Canal, NY. Originally intended to be a canal, the project was abandoned and subsequently used by the Hooker Chemical Company to dump industrial chemical waste between 1942 and 1953. Approximately 21,000 tons of toxic chemicals were buried at the site. In the 1950s, the land was sold to the Niagara Falls School Board, and homes and a school were constructed over the former landfill.

In the 1970s, residents of Love Canal began noticing foul odors and strange substances surfacing in their yards, and experiencing various health problems. Investigations revealed significant contamination of the soil and groundwater, with chemicals leaching into basements and contaminating indoor air. The site was found to contain a variety of toxic substances, including dioxins, benzene, polychlorinated biphenyls (PCBs), chlorinated hydrocarbons, and volatile organic compounds (VOCs).

The health effects on the residents were profound and varied. Short-term effects included skin conditions like rashes and burns from contact with contaminated soil and water, as well as respiratory problems such as chronic coughs and breathing difficulties from inhaling chemical vapors. The long-term effects were even more severe, with elevated rates of leukemia and other cancers, high incidences of birth defects, miscarriages, stillbirths, and neurological issues like headaches, dizziness, and memory loss. Children exposed to the contaminants showed signs of developmental delays and behavioral problems.

The growing health crisis prompted the government to act. In 1978, President Jimmy Carter declared a federal health emergency, leading to the evacuation of over 800 families. The Love Canal disaster was a significant factor in the establishment of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as the Superfund program, aimed at cleaning up contaminated sites across the United States.

IMAGE: MARK KITCHELL (DIRECTOR). (2012) A FIERCE GREEN FIRE: THE BATTLE FOR A LIVING PLANET [FILM] ZAP ZOETROPE AUBRY PRODUCTIONS

Extensive remediation efforts were undertaken at Love Canal, including the construction of a containment system to prevent further leaching of chemicals. Many homes were demolished, and the affected area was fenced off and designated as uninhabitable for several years. The site continues to be monitored for residual contamination and potential health risks (McKinley, 2023).

EFFECTS ON BIOTA

Microbiota and microorganisms in soil systems are strongly influenced by polluted soils. Several studies have shown decreasing microbial activities and lowered biodiversity in heavy metal-contaminated soils (Bamborough & Cummings, 2009; Gremion et al., 2003). Several heavy metals have been proven to have a negative effect on biomass, species richness, reproduction rates, and activity within microbial communities in forest landscapes (Chodak et al., 2013; Frostegård et al., 1993; Tyler et al., 1989).

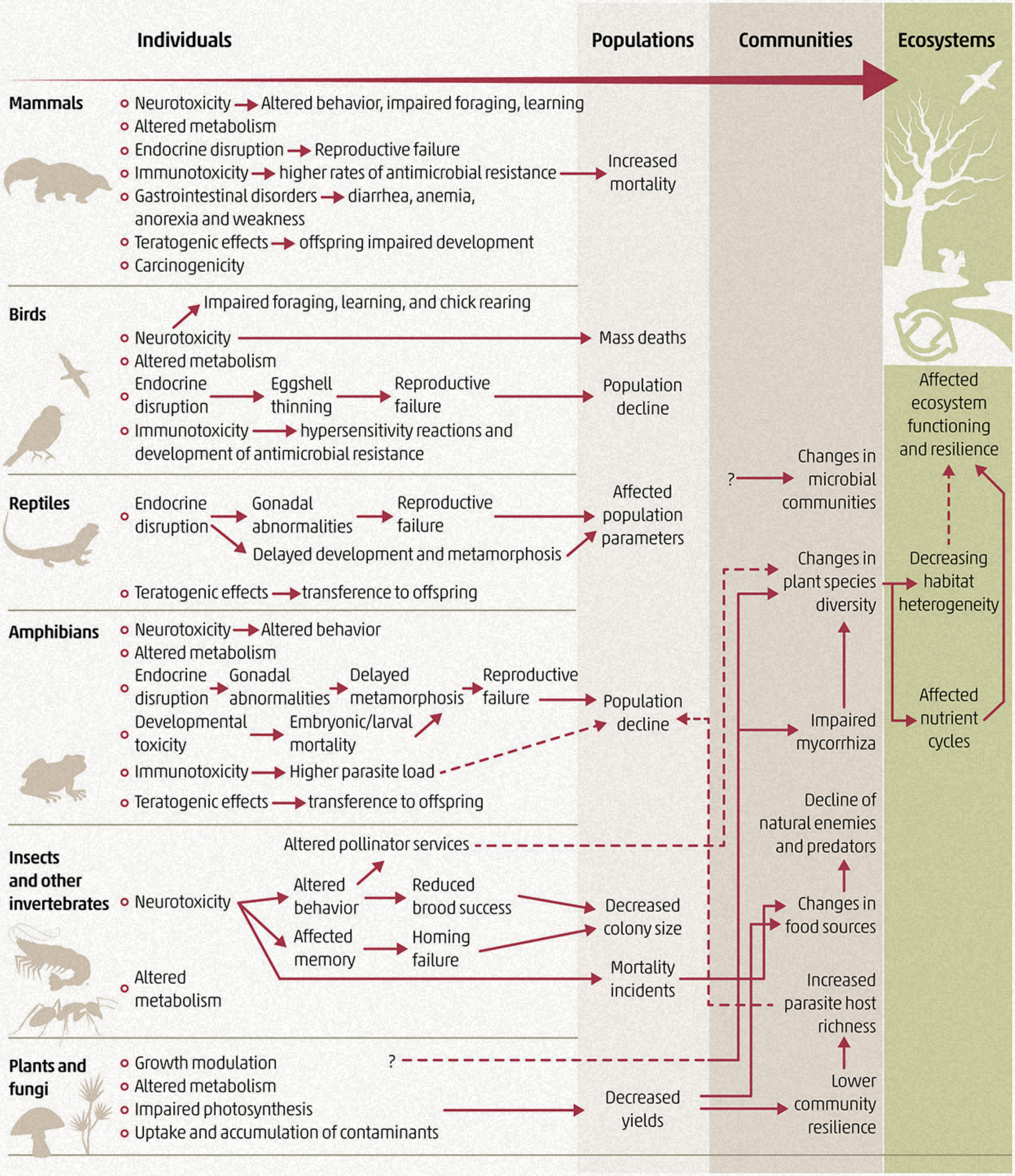
The effects of soil contamination on larger plant species are not as prominent as those on micro- and macroorganisms (Hernández & Pastor, 2008). However, also larger plants show a decrease in biodiversity and community structures (Dazy et al., 2009). Uptake of trace elements and organic contamination can result in yield decreases, growth inhibitions, root elongation, seed germination, and photosynthesis rates. These results are found in laboratory and field studies. Furthermore, a general reduction in biomass and significantly increased concentrations of stress-related proteins are reported (Ahsan et al., 2007; Chibuike & Obiora, 2014). This is not only affecting the ecosystems themselves but leads to a reduction in food production and threatens food security in vulnerable regions, dependent on industrial production.

Studies concerning the impact of soil contamination on larger fauna, likewise show changes in premature deaths, decreased reproduction, impeded growth, and higher concentrations of stress-related proteins and hormones. Besides that, genetic alterations and changes in cell structures are reported. The effects fluctuate based on dietary regimes and exposure time of the specific contaminants. Younger and diseased individuals are more vulnerable to negative effects due to soil contamination (Chrzan, 2017).

Contamination affects all elements within the ecosystem it finds itself in. Ecosystems have grown resilient to these threats like pollution, climate change, habitat fragmentation, and overexploitation to some extent. By altering their community structures and avoidance strategies, ecosystems act upon their changing environments. These strategies can be observed throughout all levels of the trophic web (Köhler & Triebskorn, 2013). A study by Kozlov & Zvereva (2017) presented ecotoxicological responses in ecosystems across 206 point-source pollution locations across 36 different countries. The reported responses varied widely, depending on the source, contaminant type, exposure duration, climate, and ecological community. Although all cases showed different responses to the contamination present, they all showed reduced body size and decreased survival rates when proximity to the contamination source increased.

Harmful effects as a result of contamination throughout the trophic web can have major impacts on the overall ecosystem. Decreased yields in plants and fungi lead to lower community resilience and changes in food sources, resulting in changing food sources for other animals. Affected insects and vertebrates have their effect on pollination, in turn having their effects on plant biodiversity and growth (Köhler & Triebskorn, 2013). However, ecosystems will find a new balance over time. Numerous sites across Europe have been abandoned for decades, leading to natural regeneration that has transformed them into significant reservoirs of species and biodiversity. Traditional remediation activities are not always beneficiary for local ecosystems, however. Although, removing the toxic elements, cleaning activities such as digging and physical or chemical treatment disturb these reservoirs and again disrupt the ecosystems that have formed.

Although soil contamination still has harmful effects, many plant species tolerate specific concentrations of contamination in their soil. Over time, these species have created mechanisms to mitigate the negative impacts of these contaminants or created ways to immobilize or degrade these contaminants, minimizing the negative impacts of soil contamination (Singer et al., 2007).



HOW CONTAMINATED SOILS AFFECT ENTIRE ECOSYSTEMS

IMAGE: KÖHLER & TRIEBSKORN, 2013

PHYTOREMEDIATION

Phytoremediation and phytotechnologies involve the use of vegetation in order to remediation, contain, or prevent contaminants in soils, water, and air (Salt et al., 1998; The Interstate Technology & Regulatory Council (ITRC), 2009). The ITRC also defines phytotechnologies as a set of planning, engineering, and design tools and cultural practices that can assist in working with contaminants in current and future individual sites, the urban fabric, and regional landscape (Singer et al., 2007).

Currently, over 400 flora species are identified as possessing the potential to remediate soil and water systems. Pennycress (Thlaspi), brassica, Sedum alfredii, and thale cress (arabidopsis), are among the most intensely studied species in terms of remediation potential. Phytoremediation is a topic that is still popular within research and that is still evolving. More plants are expected to be discovered with phytoremediation capabilities. Besides that, recent advantages in biotechnology are expected to assist phytotechnologies by developing and ameliorating hyperaccumulators through hybrid breeding and genetic modifications (Aken & Doty, 2009).

Phytoremediation can be applied to a wide range of organic and inorganic pollutants and form a cost-effective and sustainable alternative to traditional remediation techniques that require soil excavation, transportation, and or costly and polluting chemical processes. Phytoremediation and phytotechnologies are umbrella terms that encompass multiple methods for soil remediation and the processing of contaminants. The different mechanisms found across various plant species are shortly addressed below:

Phytodegradation

Phytodegradation involves the uptake and breakdown of contaminants by plants into smaller, often non-toxic metabolites. These metabolites, integral to the plant's growth process through phytometabolism, are produced during photosynthesis or via internal enzymes and microorganisms. The plant thereby transforms harmful substances into benign compounds, facilitating safer environmental conditions.

Rhizodegradation

Rhizodegradation occurs when contaminants are decomposed into harmless metabolites by root exudates and the surrounding soil microbiota. Although plants do not directly break down the contaminants, they play a crucial role by exuding phytochemicals and sugars that enable soil microorganisms to metabolize these substances effectively, thus detoxifying the soil.

Phytovolatilization

In phytovolatilization, plants absorb contaminants and release them as gases, effectively removing them from the site of contamination. The contaminants, which can be in gaseous, liquid, or solid states, are not broken down but are emitted gradually to minimize impact on air quality. Sometimes, these volatilized gases are byproducts of prior phytodegradation processes.

Phytometabolism

Phytometabolism involves the conversion of essential nutrients like nitrogen, phosphorus, and potassium into biomass necessary for plant growth and photosynthesis. This process often integrates with phyto- or rhizodegradation, wherein organic contaminants are broken down into beneficial inorganic nutrients that the plant can utilize.

Phytoextraction

Phytoextraction is the process by which plants absorb pollutants and sequester them in their tissues. Unlike phytometabolism, the contaminants are not used for biomass production but are stored in above-ground parts. When combined with phytodegradation, contaminants are fully removed from the site. Harvesting and disposing of these plants is essential, and depending on contamination levels, they can be repurposed for biofuels, phytomining, or other materials.

Phytohydraulics

Phytohydraulics refers to the ability of plants to draw groundwater, along with its contaminants, towards their roots through a strong hydraulic pull. This mechanism can either attract contaminants for phytoremediation or prevent the spread of polluted groundwater. Often, phytohydraulics is used alongside other phytomechanisms like phytoextraction and phytodegradation to effectively manage and eliminate pollutants.

Phytostabilization

In phytostabilization, plants and their root systems physically secure contaminated soil, preventing its movement and reducing the bioavailability of contaminants. The plants may also secrete phytochemicals that bind with the pollutants, further immobilizing them and mitigating environmental risks.

Phytoaccumulation

Phytoaccumulation involves the capture and retention of airborne pollutants on the surfaces of leaves and woody tissues. This process allows plants to filter contaminants from the air, holding them in place and preventing their dispersal, thereby improving air quality.

Rhizofiltration

Rhizofiltration refers to the use of plant root systems to filter contaminants from water, particularly in wetlands or during stormwater management. Plants release oxygen and organic matter into the soil, creating binding sites that capture and store pollutants, thus cleansing the water of harmful substances.

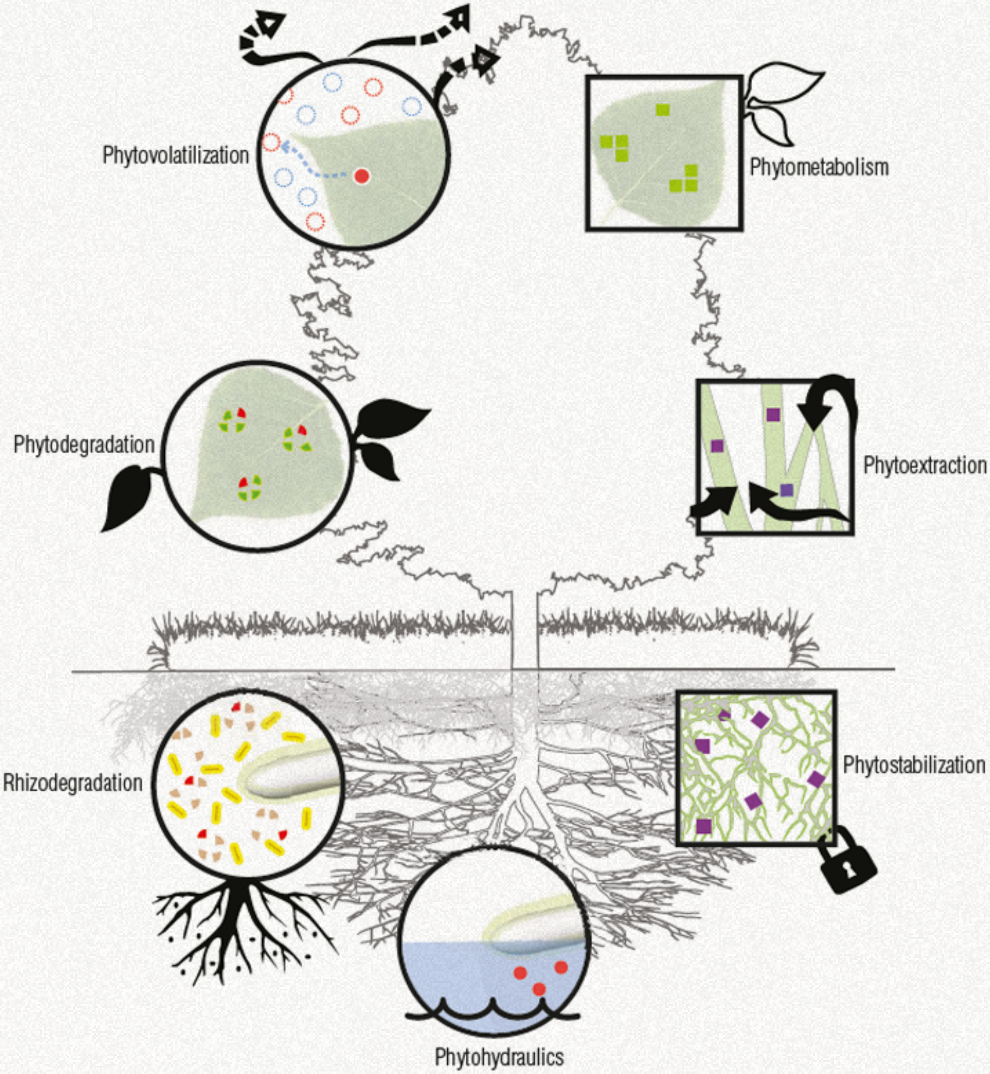
PRACTICAL LIMITATIONS AND OPPORTUNITIES

Technical and economic considerations

Although forming a sustainable and environmentally friendly remediation technique, phytotechnologies require a large timespan and are seen as a long-term solution. Phytotechnologies often take multiple years to even decades before becoming completely functional. Traditional remediation techniques come with higher initial costs, but offer far quicker results and allow for faster reuse of the land (Gatliff, 1994).

During phytoremediation, the vegetation gradually absorbs contaminants from the upper layers of soil. Remediation of the uppermost meter of soil typically requires timeframes that can exceed a decade. Effective economic strategies for phytoremediation require careful long-term planning and large-scale implementation. Sites smaller than one hectare are generally considered financially unfeasible. The Havenstad case in Amsterdam provides an effective example of the right implementation of phytoremediation. At this location, construction is planned to begin after 2029 and the area is expected to accommodate over 100,000 people, initiating phytoremediation in the short term could prove economically viable (Grotenhuis et al., 2022).

The feasibility of phytotechnologies is heavily dependent on soil composition factors such as pH, soil age, contamination concentration, moisture levels, and temperature. Contaminant and bioavailability complement the important variables influencing the effectivity of phytoremediation. For phytoremediation to be effective, contaminants must be mobilized so that they can be accumulated by plants. Bioavailability is the extent to which a contaminant can be accumulated by



OVERVIEW OF THE DIFFERENT PHYTOTECHNOLOGIES

IMAGE: PHYTOMECHANISMS: SUMMARY DIAGRAM, FROM: KENNEN, K., & KIRKWOOD, N. (2015). PHYTO: PRINCIPLES AND RESOURCES FOR SITE REMEDIATION AND LANDSCAPE DESIGN, P.41, FIGURE2.13A.

vegetation. The chemical state and form of the contaminants, soil pH, presence and concentration of other elements, soil porosity, and overall contaminant concentration influence this bioavailability (Alexander, 2000).

In order to increase bioavailability, chelants can be applied. However, this method is not without risk. Applying chelants to contaminated sites can result in leaching of heavy metals into groundwater, further increasing the environmental harm. Additionally, using chelants comes with extra costs and the impact of chelants on soil biota is still uncertain. Avoidance of these chelants is therefore recommended (Chaney et al., 2007; Evangelou et al., 2007).

For inorganic contaminants, annual harvesting and appropriate waste disposal are necessary. Adequate processing of contaminated biomass can be costly and labor-intensive. The exact treatments are dependent on the contaminant concentrations. In some cases, this biomass can be disposed of at a local landfill, but higher biomass with high contamination concentrations should be disposed of in a hazardous waste facility.

Phytotechnologies implementation is highly complex and site-specific, posing significant limitations to its practical application. This complexity arises from the need to tailor phytoremediation to the unique characteristics of each contaminated site, which includes understanding the soil composition, landscape features, climate conditions, and the existing ecosystem. Each of these factors influences the selection and effectiveness of the plants used for remediation. The choice of plants is crucial and requires extensive knowledge, as they must be selected based on their ability to tolerate and accumulate specific contaminants, their adaptability to local soil and climate conditions, and their compatibility with the existing ecosystem. For instance, some plants may be excellent at accumulating heavy metals but may not thrive in the local climate or soil type.

TOP-LEFT: PHYTOREMEDIATION COMBINED WITH WATER RETENTION IN PARQUE RACHEL DE QUEIROZ IN BRAZIL [PHOTOGRAPH], BY JOANA FRANÇA, ARCHDAILY (HTTPS://WWW.ARCHDAILY.COM/985558/RACHEL-DE-QUEIROZ-PARK-ARCHITECTUS-S-S).

TOP-RIGHT: PHYTOTECHNOLOGY IN THE PUBLIC SPACE ALONG THE GOWANUS CANAL IN BROOKLYN, NY [PHOTOGRAPH], BY DLANDSTUDIOS (HTTPS://DLANDSTUDIO.COM/GOWANUS-CANAL-SPONGE-PARK-PILOT).

Social and ecological considerations

Besides technical considerations, the implementation of phytotechnologies can result in a lot of social and ecological benefits. The presence of nature, especially in the form of trees and large plants, improves mental health. Integration of green elements in the urban fabric is an essential element of livability and human well-being (Barton & Rogerson, 2017). Additionally, phytoremediation offers potential beneficial side effects, such as erosion control, carbon sequestration, battling the urban heat island effect, and noise buffering (Dietz & Schnoor, 2001; Doty et al., 2007).

Implementing phytoremediation plant species offers benefits beyond soil and water remediation. By strategically integrating these plants into green infrastructure, we can significantly enhance local biodiversity and other ecosystem services. The selection of plant species is crucial and complex, requiring careful consideration of factors such as native versus non-native species, hyperaccumulators, soil-plant interactions, and interactions with microorganisms. Poor choices in plant types and locations can severely disrupt existing ecological systems.

However, safety and social safety considerations must be accounted for when introducing these larger plants in urban areas. Large trees and dense vegetation in urban areas can contribute to feelings of unsafety among residents and passersby through several mechanisms. The presence of extensive foliage and substantial tree canopies can obstruct visibility, creating visual barriers that limit line of sight. This reduction in visibility can obscure potential threats, increasing the perceived likelihood of criminal activity or unwanted encounters, resulting in an increased sense of vulnerability and perceived unsafety in the area.

Furthermore, when greenery is introduced, adequate maintenance is essential. Poorly maintained or overgrown vegetation signals a sense of neglect and disorder. Following the broken windows theory, neglected maintenance makes areas and neighborhoods more prone to criminal behavior, further amplifying these feelings of insecurity.

IMAGE: IMAGE OF DE CEUVEL, AMSTERDAM [PHOTOGRAPH], BY SEBASTIAN VAN DAMME, DELVA LA (HTTPS://DELVA.LA/PROJECTEN/DE-CEUVEL).

PRACTICAL CONSIDERATIONS

Different contaminants require different phytoremediation strategies. Understanding the specific mechanisms involved and how different plants interact with various contaminants is essential but complex. Additionally, the introduction of non-native species for phytoremediation can disrupt local ecosystems, leading to unintended ecological consequences, making it preferable to use native species, which requires comprehensive knowledge of the local flora and its interactions with the contaminants. Once contaminants are absorbed, the plants used in phytoremediation become hazardous waste themselves, necessitating careful planning for their proper management and disposal to prevent secondary contamination.

Phytoremediation is not a set-and-forget solution; it requires ongoing monitoring to assess the progress of contaminant removal and the health of the plants, along with maintenance activities such as watering, fertilizing, and managing plant health. Implementing phytoremediation effectively demands a high level of technical expertise, including knowledge of plant physiology, soil science, environmental chemistry, and ecological interactions, often necessitating multidisciplinary teams. These complexities and knowledge-intensive requirements can pose limitations, such as a high initial knowledge requirement, uncertain outcomes due to variability in site conditions and plant responses, and the time-consuming nature of the process compared to other remediation technologies. Additionally, regulatory frameworks and public acceptance may not always support its use. While phytoremediation offers a sustainable and environmentally friendly approach to soil remediation, its implementation requires extensive site-specific knowledge, multidisciplinary expertise, and careful planning, which can limit its practical application.

LANDSCAPE FRAGMENTATION AND LAND COVER CHANGE

ECOSYSTEM SERVICES

The various benefits that (natural) ecosystems provide to human societies are defined as ecosystem services (ES) (Costanza et al., 1997). These ES are essential for human survival and well-being, as these processes and functions sustain life on Earth. ES as a concept emphasizes the interrelationship between ecological health and human prosperity and highlights the need for adequate maintenance and management of our natural landscapes (Millennium Ecosystem Assessment, 2005).

Generally, ES are classified into four main categories: provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment, 2005).

Provisioning services

The provisioning services refer to all the tangible products we consume and obtain from ecosystems. They include, but are not limited to food, fresh water, wood, fiber, genetic resources, and medicines. As these products from provisioning services are often directly consumed by humans and are tangible, provisioning ES are the most visible and economically the most quantifiable type of ES.

Regulating services

The regulating ES encompass all natural processes that regulate environmental and natural conditions. These processes include climate regulation, water purification, flood control, pest and disease management, and pollination. These ES are focused on maintaining balanced natural systems.

Cultural services

Cultural ES are all non-material benefits that people obtain from ecosystems through recreation, spiritual enrichment, aesthetic experiences, education, etc. ES in this category contributes to cultural identity, mental well-being, and social cohesion.

Supporting services

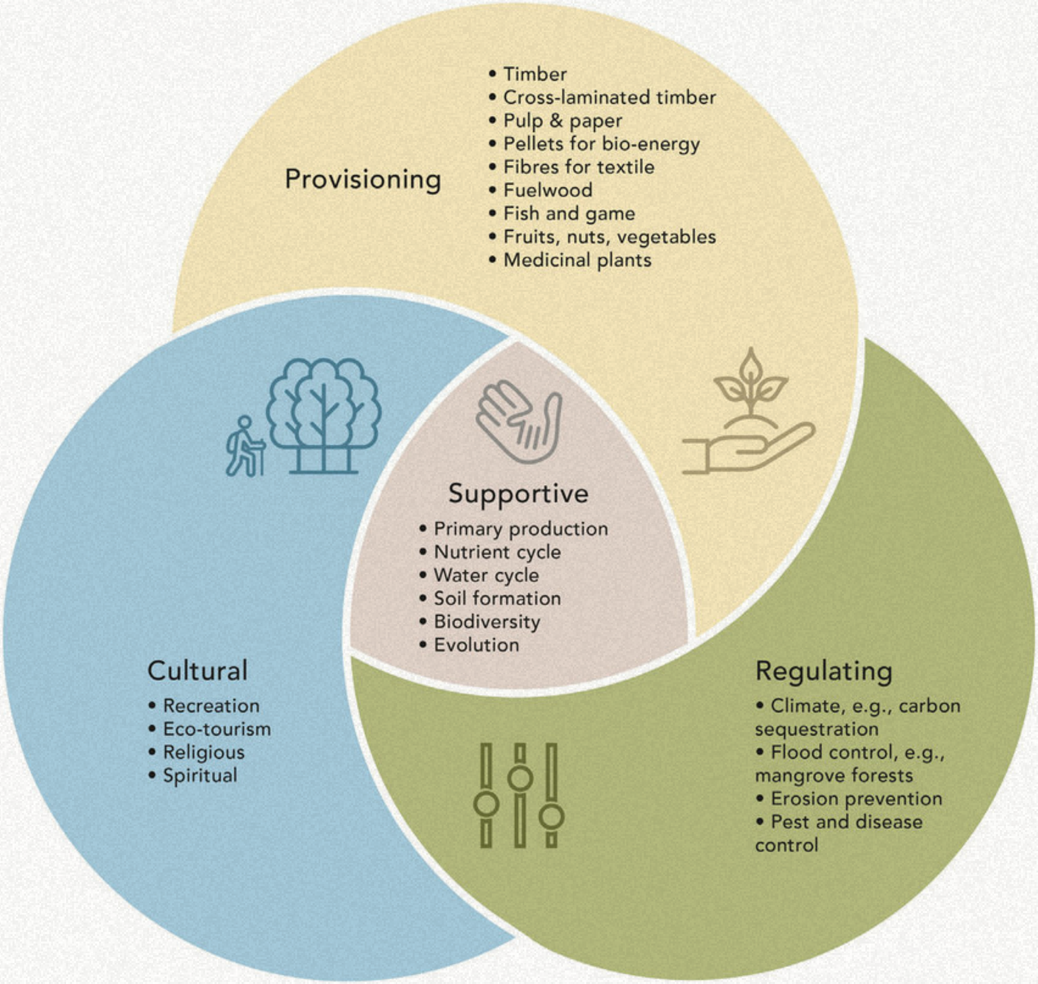
The supporting services form the basis of all other ES. They underpin the other three categories and do not directly target humans but are critical for the functioning of ecosystems and the provisioning of other services. Supporting ES include but are not limited to soil formation, nutrient cycling, water cycling, biodiversity, and primary production (Costanza et al., 1997).

The scheme from Kramer et al. (2022) on the next page presents the different types of ES and their relationships.

ES in spatial planning

Knowledge about ecosystem services provides a framework for policy-makers, land managers, and the wider public to debate about sustainable land management (Ghazoul, 2007). However, Kowalczyk et al. (2019) mention three main problems related to the application of ES in land-use planning: 'multi-scale', 'multi-user', and 'multi-service'.

Ecosystems are provided and used at multiple spatial scales. Mapping and evaluating the ES on all these different scales is time-consuming and impossible to predict. Besides that, there is a disbalance in natural units and administrative units. As spatial planning happens within the administrative boundaries, ES acts within natural boundaries, which often extend beyond the administrative boundaries. This results in difficulties in predicting the effects of the implementation of spatial plans for ecosystems and their services (Bragagnolo & Geneletti, 2012). Bastian et al. (2012) back these statements and even speak about the temporal dimension across multiple scales. As the provision and benefits of ES may vary over space and time, it is difficult to value the impact of spatial planning for ES.



CATEGORIZATION OF ECOSYSTEM SERVICES FOLLOWING THE MILLENIUM ECOSYSTEM ASSESSMENT

The second problem for integrating ES in spatial planning lies within the different users and stakeholders. As some of the ES are beneficial to all users, e.g., climate regulation or air pollution control, other benefits derived from the ecosystem vary between stakeholders. Valuing the different ES within a territory with different stakeholders is difficult, especially since the number of stakeholders linked to ES are usually extremely high (Bastian et al., 2012; Lamarque et al., 2011).

The last problem is related to the multiple services that an ecosystem provides. An ecosystem usually provides multiple ES at once and they can change over a temporal and/or spatial scale. Therefore, to implement the impact of ecosystems in spatial planning an extremely extensive trade-off matrix is needed, which is almost impossible due to the multi-scale and multi-user problems described above (Bragagnolo & Geneletti, 2012).

IMAGE: KRAMER ET AL. (2022), . GENERAL CATEGORIES OF FOREST ECOSYSTEM SERVICES FOLLOWING THE CLASSIFICATION OF THE MILLENNIUM ASSESSMENT. FROM ROADMAP TO DEVELOP A STRESS TEST FOR FOREST ECOSYSTEM SERVICES SUPPLY GATHERED FROM HTTPS://WWW.SCIENCEDIRECT.COM/SCIENCE/ARTICLE/PII/S2590332221007272#FIG1

LANDSCAPE ECOLOGY

The field of landscape ecology focuses on the patterns and processes that take place within a heterogeneous landscape of different ecosystems (Loreau et al., 2003). Forman & Godron's (1986) concept of patches and structural components is a foundational concept within landscape ecology and beyond. Their theory categorizes the landscape into three main components: patches, corridors, and the matrix.

Patches are relatively homogeneous areas in terms of vegetation, soils, and other ecological factors, and differ from the surrounding landscape. These patches can be natural or human-made and vary in shape, size, and composition. These patches can be viewed as individual habitats for various species. Corridors are the linear landscape elements that connect these different patches. Their main function is to facilitate the movement of species between habitats and provide pathways for gene flow or ecological processes. Corridors can be rivers, riparian structures, hedgerows, roadsides, etc. The background that facilitates this composition of patches and corridors is called the matrix. The matrix can be composed of different landscapes and land cover types but is typically less suitable as a habitat in comparison to the patches.

The concept of landscape ecology helps in conversation and communication about natural landscapes and landscape structures and has extensively been integrated into assessment frameworks for ecological networks in urban and non-urban landscapes (Egerer & Anderson, 2020; Franco & Magalhães, 2022).

LANDSCAPE CONNECTIVITY

Connectivity between the different patches is a vital element within ecological landscapes. Taylor et al. (1993) introduced the term Landscape Connectivity, specifically focusing on this issue. Landscape connectivity has a direct influence on the stability and integrity of the (individual) ecosystems and the biodiversity (Clergeau & Burel, 1997; Forman & Collinge, 1997; Taylor et al., 1993). Since its introduction, the concept of landscape connectivity has established itself as an essential element within conservation planning, landscape management, and ecological assessments (Nikolakaki, 2004; Saura & Pascual-Hortal, 2007). By incorporating landscape connectivity in ecological planning and management strategies, it is possible to enhance the resilience of ecosystems and promote biodiversity and species survival in a targeted manner.

A well-connected ecological landscape promotes the dispersal and free movement of organisms between the different habitats in the landscape. The movement of organisms is fundamental for all ecological and biological processes and is studied by a variety of ecological disciplines. In landscape ecology, free movement has a positive effect on gene flow and reproduction of species, as more (and different) organisms are able to get in contact with each other. The connectivity of landscapes is often reflected in biodiversity and species survival rates, having a positive effect on genetic diversity and population dynamics (Cushman, 2006; Fahrig, 2003).

Landscape connectivity describes the extent to which the landscape facilitates various ecological processes to take place. Animal movement is often used as a reflective variable for general landscape connectivity. Animal movement behavior is influenced by a variety of biotic and abiotic factors. Since landscapes are subject to change, this establishes a complex relationship between the movement of individuals and the landscape (Lorimer, 2015; Wiens & Milne, 1989). Besides the temporal (and seasonal) scale of changing landscapes, the spatial scale is an important factor in landscape connectivity. This relates to the spatial distribution of habitats, but also to the scale at which organisms interact with the landscape pattern as not different species each have their requirements regarding habitat size and dispersion distance over which they can travel between habitat patches.

LANDSCAPE FRAGMENTATION

The connectivity of natural landscapes is under threat globally. This threat derives from the same anthropogenic activities that cause the contamination of our soils, including industrial production, infrastructure construction, urbanization, and agricultural expansion. Our high demand for products, energy, and food, results in higher space demand for this production to take place. This land use conversion and land cover change often comes at the expense of natural areas and habitats. This not only results in shrinking habitats and nature but also fragments the landscape, breaking it up into separate discontiguous patches. Landscape fragmentation is the physical disintegration of continuous habitats into smaller units or patches (Fahrig, 2003), most often caused by urban or transport network expansion (van Bohemen, 1998). This landscape fragmentation impedes free species movement and ecological processes, due to the decreased connectivity of the natural landscape. Impacting ecosystem health, biodiversity, and ES provisioning.

These trends in land use conversion and land cover change are visible throughout the EU. Although in Central Europe and Denmark, these urbanization and industrialization trends have mostly ended, and afforestation is currently the primary land use conversion. Southern Europe still shows a lot of agricultural and urban expansion taking place (Baranzelli et al., 2013).

The EU biodiversity strategy for 2030 (European Commision, 2020) aims to protect and restore nature, including by tackling fragmentation. Fragmentation also impacts the implementation of the EU strategy on green infrastructure and achieving the long-term objectives of the EU common agriculture policy, namely the sustainable management of natural resources, climate action, and balanced territorial development.

CAPTION

IMAGE: GARDENERS COACH (N.D) LANDSCAPE FRAGMENTATION SHOWN IN AERIAL VIEW, IMAGE GATHERED FROM: HTTPS://GARDENERSCOACH.WORDPRESS.COM/2013/03/17/HABITAT-FRAGMENTATION/, MARCH 17,2013)

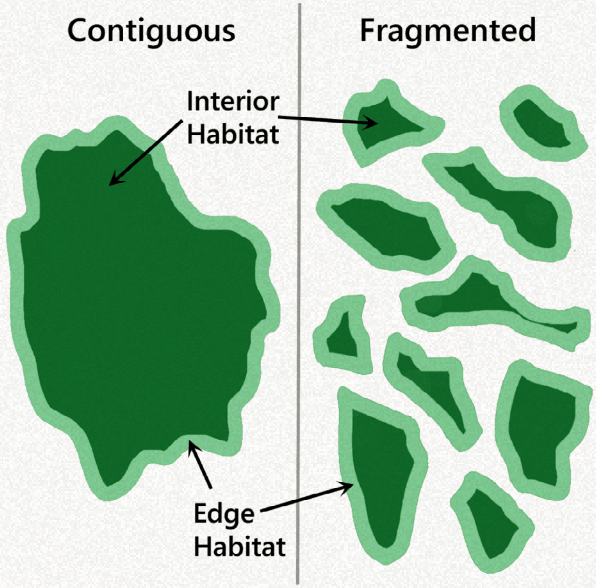
GREEN INFRASTRUCTURE (PLANNING)

The EU biodiversity strategy for 2030 (European Commision, 2020)highlights the EUs focus on protecting natural resources. This is also reflected in the EU Green Infrastructure Strategy (European Commission, 2019), where the EU promotes and guides the integration of nature-based solutions and green infrastructure into spatial planning.

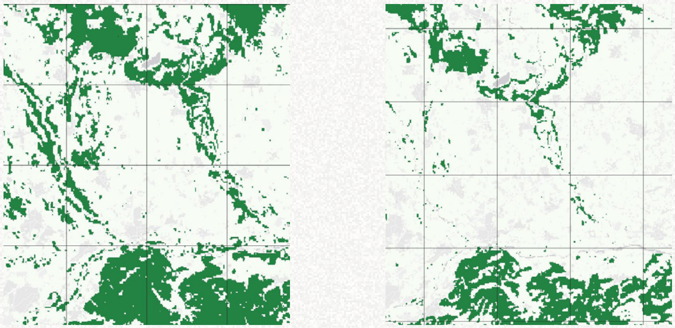
Green infrastructure (GI) is defined by the EU as "A strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services, while also enhancing biodiversity" (European Commission, 2019). GI is a sustainable approach that attempts to provide multiple ES simultaneously. Together with the cost-effectiveness of GI, these are the main attributes that make it often more attractive in comparison to traditional 'grey' infrastructure.

GI consists of a wide range of different spatial interventions, across different spatial and temporal scales. Examples vary from sedum and green roofs to battle urban heat and contribute to the urban water cycle, to restoring floodplains to increase resilience for flooding whilst improving natural habitats and supporting biodiversity. GI can be found in all types of landscapes, ranging from urban GI in the form of parks, green roofs, and permeable pavements to Natura 2000 areas in rural and natural landscapes, fish ladders and reedbeds along riverscapes, and crop-rotation and agroforestry in agricultural settings.

The planning of GI is not only focused on the (local) provisioning of these ES themselves but also on improving ecosystem health and landscape connectivity. The multiscalar benefits of GI planning are one of its main attractions, also contributing to scaling up investments and funding from the EU. GI planning is essential for sustainable spatial planning and development on the local and regional scale.



LANDSCAPE FRAGMENTATION AND ITS EFFECT ON HABITAT EDGES



LAND COVER CHANGE RELATED TO PIEMONTESE FORESTS IN BETWEEN 2015 & 2019

TOP: CANADIAN CENTRE FOR TRANSLATIONAL ECOLOGY (2019), IMAGE GATHERED FROM: HTTPS://CCTE.CA/RESOURCES/FIG5.1.HTML
BOTTOM: OWN WORK, DATA FROM FOREST LAND-COVER IN CENTRAL PIEDMONT, FROM COPERNICUS LAND MONITORING SERVICES 2015-2019.

MULTI-SCALAR SPATIAL DEVELOPMENT

Multi-scale spatial planning and development tend to be challenging. Multi-scalar development involves communication and collaboration between multiple levels of governance (local, municipal, regional, national, etc.), which can lead to inefficiencies and conflicts (Zonneveld & Stead, 2024). This is also reflected in the differences in frameworks and policies that are applied across governance levels. The alignment of policies, regulations, and decision-making processes complicate and decelerate multi-scalar developments (Bocca, 2024; Pataki et al., 2011). Besides process-based challenges, the alignment of goals and preferences is challenging. Local communities hold and prioritize specific needs and preferences that may conflict with large-scale planning objectives (Fernández-Pablos et al., 2021). Differences in stakeholders and objectives impede structural multi-scalar planning. Effective spatial planning is based on the engagement of multiple stakeholders, including those from governance, the private sector, and local communities. The differing interests and power dynamics that occur in multi-scalar planning are often challenging (Bocca, 2024). Financial resources and responsibilities can further impede successful multi-scalar development. Differing monetary constraints or possibilities, financial transparency, and spreading of financial risks and responsibilities are presented as other challenges in multi-scalar development (Horak, 2013; Hüesker & Moss, 2015; Scott et al., 2013).

PROBLEM STATEMENT

Current global trends in urbanization, industrialization, and the intensification of agricultural practices are posing significant threats to our environment. Increased production demands more resources, energy, and transportation, leading to a surge in waste generation. Poor management of these anthropogenic activities has resulted in severe contamination and pollution of soil, water, and air. Europe alone has 2.8 million potentially contaminated sites, with around 340,000 requiring urgent remediation measures. Contaminated soils pose serious health risks to humans, increasing the incidence of cancer, neurological diseases, reproductive issues, and liver and kidney failures, among other health problems. Additionally, these soils adversely affect ecosystems by disrupting soil microbiota, reducing biomass, species richness, and microbial activities, and ultimately impacting higher plant species and overall ecosystem health.

The same human activities are leading to significant land cover changes, converting natural landscapes into artificial ones, which not only shrink but also fragment and disconnect natural habitats. Ecosystem connectivity is crucial for maintaining health and allowing gene flow and ecological processes to occur.

Phytoremediation and green infrastructure (GI) planning are proven, robust solutions to these problems. However, they each address only one aspect of the issue and are focused on specific spatial scales: regional for GI planning and local for phytoremediation. Multi-scale design faces significant challenges in aligning goals, regulations, and stakeholder interests. Local planning tends to prioritize specific issues that may conflict with regional objectives. Furthermore, effective communication and coordination between different authorities across scales are major hurdles.

There is a lack of a comprehensive framework or approach that connects these scales and integrates local objectives with regional goals. This gap results in missed opportunities for implementing nature-based solutions and phytoremediation effectively. Consequently, many sites in need of remediation are either not addressed or are handled in a non-sustainable manner. Addressing this gap is essential to enhance the sustainability and effectiveness of environmental remediation efforts.

GOALS AND AIMS

The primary goal of this thesis is to develop and present an integrated framework for sustainable spatial development, focusing on GI and soil remediation. This proposed framework bridges the gap between local and regional planning efforts by aligning small-scale interventions and objectives with the broader regional goal of landscape connectivity. This creates a framework that aligns small-scale objectives with broader regional goals, ensuring a coherent approach to addressing contamination and land use challenges through nature-based solutions and phytoremediation. With this framework, multiple aims are pursued:

ENHANCING COMMUNICATION AND COORDINATION:

Put in place effective means of communication and coordination between the local authorities, regional bodies, and stakeholders. Exchanging information, collaborating, and joint decision-making using information-sharing platforms

ENCOURAGING SUSTAINABLE REMEDIATION PRACTICES:

Implementation of sustainable remediation practices to encourage environmental health and human well-being. This includes modern, green ways of cleaning sites contaminated by pollutants and the restoration of natural habitats.

OPTIMIZING PHYTOREMEDIATION AND GI-PLANNING:

Implementation and optimization of phytoremediation and GI planning at a local and regional level. To optimize the application of such nature-based solutions for improved health of ecosystems and better remediation of soil contamination.

IMPROVING ECOSYSTEM CONNECTIVITY:

Aim at increased connectivity of ecosystems by minimizing the impact derived from changes in land cover. In this area, planning and performance measures that conserve natural corridors and habitats for restoration are included.

ALIGNMENT WITH THE UN SUSTAINABLE DEVELOPMENT GOALS

The goals and aims of this thesis align and contribute to several of the United Nations Sustainable Development Goals (SDG) (United Nations, 2022). Of the 17 SDG's, this thesis directly addresses six of them. By mitigating human exposure to harmful contaminants by means of phytotechnologies, "SDG 3": Good Health and Well-Being" is pursued. Additionally, the establishing of green corridors and the enhanced GI provides more recreational and urban green spaces, contributing to mental well-being of local communities.

The project also addresses "SDG 6: Clean Water and Salination" by remediating contaminating sites and preventing contaminants from leaching or running-off into water bodies and protecting water quality. Besides that, supporting the ecosystems and improving ES, the project improves natural water filtration and purification.

As aforementioned, the project enhances mental well-being by improving green spaces. These spaces increase urban livability and sustainability and align with "SDG 11: Sustainable Cities and Communities". Addressing soil contamination and landscape fragmentation further promotes resilience to environmental changes and further human impact.

"SDG 14: Life Below Water" and "SDG 15: Life on Land" are obviously addressed by supporting healthier ecosystems in both terrestrial and aquatic environments. Restoring contaminated landscapes is a first step, while the introduction of new and extra flora (and fauna) contributes to these ecosystems even further.

Ultimately, the approach aims on enhancing communication and collaboration between governing bodies and authorities on different spatial scales, but also on the engagement and inclusion of communities and stakeholders. Thereby the final SDG 17 "Partnership for the goals" is supported.

IMAGES: UNITES NATIONS, 2022

RESEARCH QUESTIONS

To bridge the scalar gap between the regional GI-planning and micro-scale selection of phytoremediating plant species, multiple intermediate spatial scales have to be addressed. To streamline my research, I established 7 sub-questions that are connected to these different scales. Apart from the smallest scale, all of these spatial scales contain one research question focused on the assessment of the current conditions of (the natural systems from) that scale, alongside a research question addressing optimal design methodologies for ameliorating that specific system. Cumulatively, the answers for the individual sub-questions lead to an approach on how to integrate micro-scale phytoremediation practices with regional GI planning for improved landscape connectivity.

MAIN RESEARCH QUESTION

"How can local-scale phytoremediation solutions be integrated into regional scale Green Infrastructure design?"

MAIN RESEARCH QUESTION

HOW CAN LOCAL-SCALE PHYTOREMEDIATION SOLUTIONS BE INTEGRATED INTO REGIONAL SCALE GREEN INFRASTRUCTURE DESIGN?

REGIONAL

UNDERSTANDING

What are the components of the current natural landscape structure, and how can they be enhanced? SQ1

→

OPTIMIZING

Where would a new green corridor most effectively enhance landscape connectivity? SQ2

selecting & zooming in

CORRIDOR

UNDERSTANDING

What strategies can be used to design the green corridor path based on spatial structure? SQ3

→

OPTIMIZING

Which design strategies are most effective based on ecological movement potential? SQ4

selecting & zooming in

SITE

UNDERSTANDING

What types of contaminated sites exist within the study area? SQ5

→

OPTIMIZING

What design patterns can be applied to the redesign of contaminated sites? SQ6

selecting & zooming in

PLANT

Which plant species are suitable for the selected design patterns and site-specific conditions to effectively remediate the local soil? SQ7

THE ROLE OF DATA-DRIVEN DESIGN

DATA-DRIVEN (SPATIAL) DESIGN

The concept of Data-Driven Design introduces a new approach to spatial planning and design. Incorporating advanced digital technologies and computational methods with traditional planning tools improves the efforts toward sustainable spatial development. Data-driven spatial design utilizes principles from a variety of research fields, including among many others urban informatics, Geographic Information Science (GIScience), and urban climatology. These principles are integrated into spatial design, planning, and research frameworks. This integration of data results in evidence-based decision-making, moving away from the reliance on assumptions and expectations (van Ameijde, 2023).

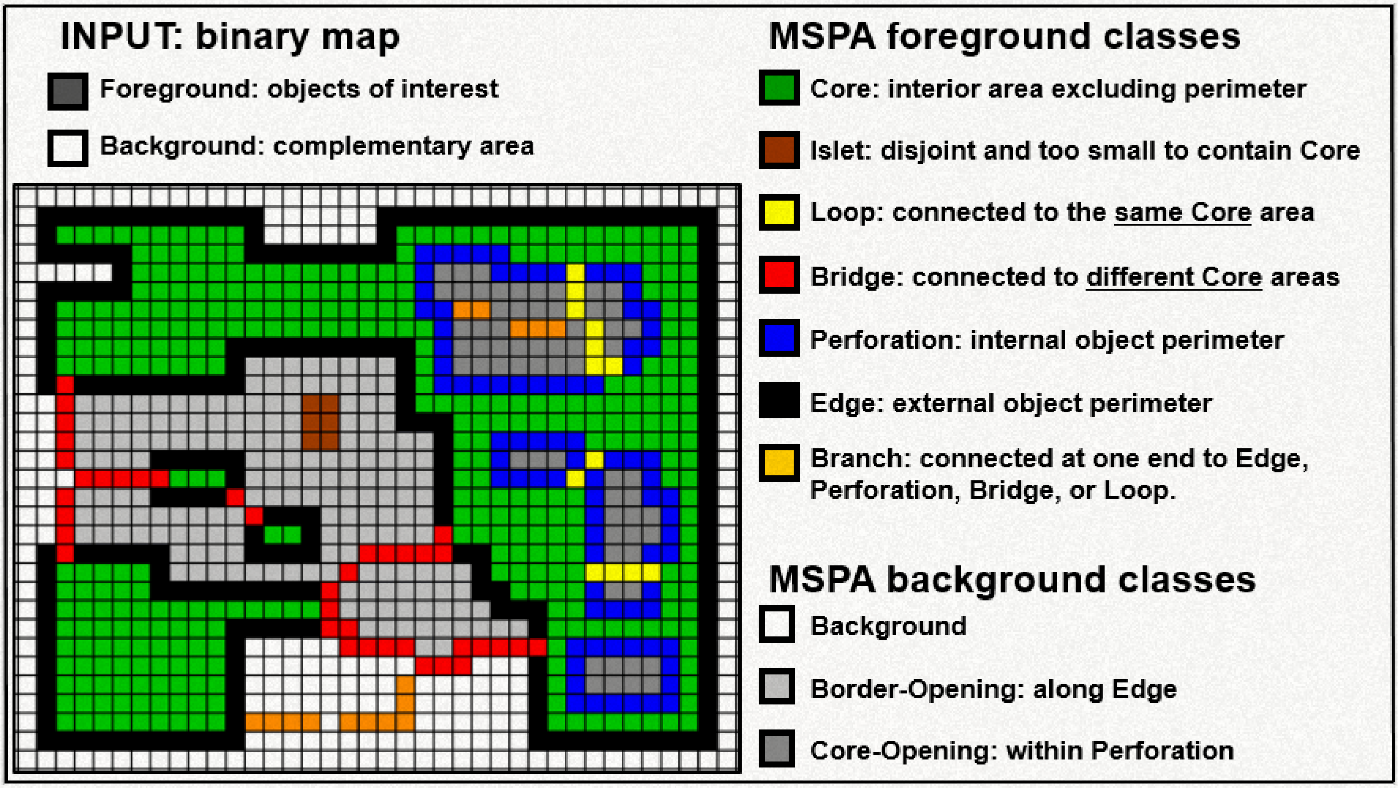
Collection and mapping data from various fields of expertise across spatial and temporal scales allows the use of computer algorithms to identify spatial relationships, patterns, or trends within the social and ecological landscapes. Modern technology provides designers with tools for generating new, systematic, and robust knowledge of urban structures, which support the design process.

When applied correctly Data-Driven Design can bridge the gap between research and design. Integrating computational and technological possibilities in the traditional design process expands the cognitive ability of the designer. Data-driven design approaches not only support a better understanding of the complex spatial challenges that the designer is faced with, but simultaneously can help in assessing, visualizing, and testing design options and possibilities (Hall et al., 2020; Snyder, 2019). As the possibilities in data-gathering and processing are endless, thorough understanding from the designer's perspective is essential to utilize data-driven design in a purposeful manner. The same accounts for visualization. As more and more data is used to support decision-making, visualization of this (spatial) data becomes more challenging.

As data becomes increasingly important in design projects, the distinction between research and design slowly disintegrates. Designers are supposed to incorporate data in their decision-making processes. In the most traditional design process, a clear distinction can be made between research-related and design-related activities. Data is used for analyzing and identifying the problem, whereafter design is used to provide creative solutions to solve these problems. However, with Data-Driven Design, the research is used throughout the design process to identify new options, simulate and assess possibilities, optimize solutions, and visualize implications (Yang et al., 2020).

In the case of GI planning, data-driven approaches provide evidence of environmental and natural conditions, including among others climate patterns, biodiversity, and land use. This data provides a basis for identifying areas in need of GI interventions and can be used for optimizing implementation efforts. Resulting in decreased time needed for planning, minimal resource use, and eventually lowered financial costs. Besides identification and optimization, these same approaches can be used for assessment and monitoring frameworks, evaluating efficacy and performance over time. Finally, data-driven design supports the establishment of clear and automated workflows, improving transparent decision-making and improvement reproducibility (Wilson et al., 2021).

The following theories and principles are used throughout the approach of this thesis to ensure the data-driven nature of the project:



EXPLANATORY IMAGE OF MSPA RESULTS ON THE PIXEL-LEVEL

IMAGE: SOILLE EN VOGT, 2009

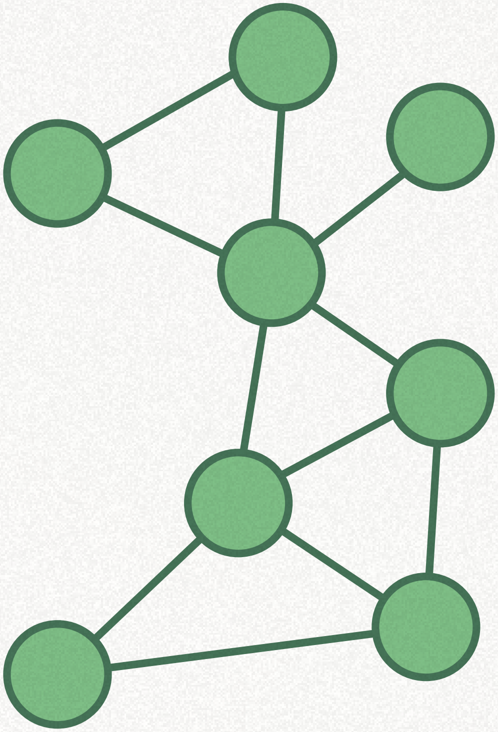
MORPHOLOGICAL SPATIAL PATTERN ANALYSIS

Morphological Spatial Pattern Analysis (MSPA) is a valuable method in the assessment of landscape structure. MSPA allows for classifying and segmenting binary patterns into seven distinctive categories. This raster-based method employs a single parameter to classify each pixel based on its spatial surroundings utilizing mathematical morphology operators (Soille & Vogt, 2009). These categories encompass cores, edges, perforations, bridges, loops, branches, and islets. The application of MSPA in ecological structures aligns with Godron & Forman's theory on landscape ecology and the structural components that make up the natural environments (L. Liu et al., 2021). Being able to classify and categorize landscape into structural elements, support a comprehensive assessment of the landscape structures.

MSPA is based on binary input maps, containing foreground pixels (byte = 1) and background pixels (byte = 0). Using morphological image processing (MIP), each pixel in this map is classified into one of the aforementioned seven categories. MIP uses a set of mathematical operations related to the shape, or morphology, of the features within the image. The class to which a pixel belongs is determined by its binary value and the values of the surrounding pixels.

MSPA is widely used in assessing landscape structures and identifying ecological sources, contributing to frameworks for improved landscape connectivity and the development of ecological network plans (Jin et al., 2022; Yeo et al., 2022). This method is scalable and is therefore applicable in various contexts. It has been used in urban GI planning at the city level, but also in regional and national conservation planning, highlighting the flexibility and applicability of this assessment method (Wang & Pei, 2020).

The application of MSPA in combination with other GIS methods has been proven useful for recognizing patterns in the spatial distribution of ecological landscape elements. Indrayani et al. (2015) have used MSPA and GIS to gain an understanding of landscape conservation strategies and the impact of land cover change, while Qian et al. (2023) have studied the distribution of haze in natural landscapes. MSPA has been proven suitable for analyzing and understanding spatial structures and identifying the individual structural components that make up this landscape.



SCHEMATIC OVERVIEW OF A GRAPH-NETWORK CONSISTING OUT OF NODES AND LINKS

NETWORKS & CONNECTIVITY

Connectivity within the natural landscapes is essential for healthy and well-functioning ecosystems. Although MSPA gives great insight into the structure of the natural landscapes and allows for identifying the individual elements that make up this structure, it does not quantify or define connectivity. Spatial patterns and structures do not allow for quantification. To be able to tell to what extent the individual elements are interconnected, a network perspective is essential.

A network is defined as a system of interconnected elements or nodes that are connected to facilitate interaction between the individual elements. In essence, a network represents a structure that enables the flow of entities, whether they are people, data, goods, or signals, across the interconnected nodes. The concept of a network extends beyond physical connections to include abstract relationships and interactions that form a complex web of interdependencies and communication pathways. Networks play a fundamental role in various domains, including social sciences, biology, computer science, and transportation, providing a framework for studying complex systems and their organizational structures (Wilson et al., 2021).

Graph theory has emerged as an effective method of quantifying the sum of patch interactions to give an overall assessment of landscape connectivity (Minor & Urban, 2008; Sierra & Feng, 2018; Urban & Keitt, 2001; Zetterberg et al., 2010). The results of graph-based analyses produce comparable results to those obtained from detailed spatially explicit habitat models (Minor & Urban, 2007), with less detailed inputs required to reflect biological realism (Calabrese & Fagan, 2004). A graph network is composed of nodes and links, each of which has defined characteristics. Nodes that are connected by links are defined as belonging to the same component. When applying graph theory to habitat connectivity, different habitat patches constitute the nodes and the movement of individuals or genetic material between patches are the links between nodes

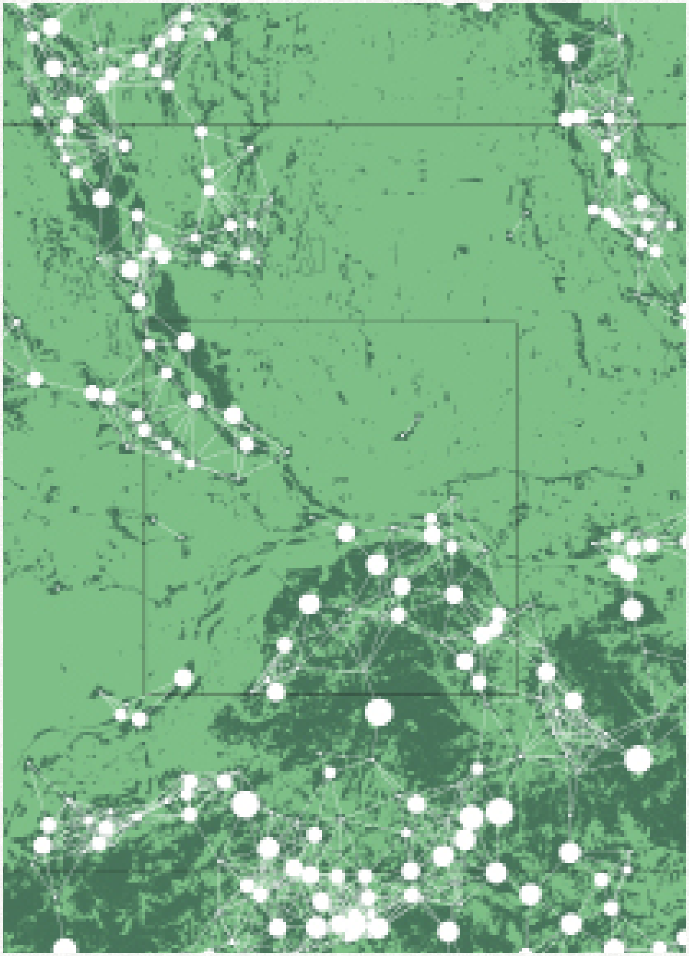
By viewing the natural landscape from a network perspective we can determine the level of connectedness between the individual elements. Various connectivity indices can be used to quantify the connectivity within graph networks. The Integral Index of Connectivity (IIC) and Probability of Connectivity (PC) are considered the most accurate and robust indices, as presented in a study by Saura & Pascual-Hortal (2007), where they evaluated nine of the most-used indices on 13 different criteria.

The IIC is a binary-based connection model. Two individual patches are linked to each other, whenever the distance between those elements is below a certain threshold value. Elements can also be linked to each other via other elements or links, as long as the distance between those elements never exceed the threshold value. The shortest amount of links needed in order to connect two individual elements determines the strength connectivity strength of the link. IIC ranges from 0 to 1.

The PC is a probabilistic model, based on the distance between individual elements and the dispersal probabilities of animal species. This probabilistic approach is less much less sensitive to uncertainties in estimating threshold dispersal distances. The level of connectivity is exponentially decreasing over distance, and so does not sharply become completely (dis)connected when crossing the threshold value. However, this approach needs dispersal distances and is in need of research and data of these dispersal distances (Rubio & Saura, 2012; Saura & Pascual-Hortal, 2007).

Using the data of these individual links, and the level of connectivity between the individual elements, it is possible to quantify the connectivity of the entire landscape as well. Using the PC, the connectivity of the landscape is defined as "the probability that two randomly placed points in the entire landscape (natural and non-natural) fall into habitat areas that are reachable from each other given the individual elements and the connections between them.

This allows determining the importance of individual elements on the landscape connectivity as well. By recalculating the overall landscape connectivity and adapting the network by adding or removing links or patches, the difference in overall landscape connectivity defines the impact of that individual added or removed network element. This allows for prioritizing patches in the network that are essential for the natural landscape, guiding conservation strategies, or determine the optimal new connections that would strengthen the network in the optimal way in terms of added landscape connectivity.



IMPLEMENTATION OF A GRAPH-NETWORK ON ECOLOGICAL LANDSCAPES. EACH NODE REPRESENTS AN ECOLOGICAL CORE. CORES WITHIN A THRESHOLD DISTANCE ARE CONNECTED BY LINKS.

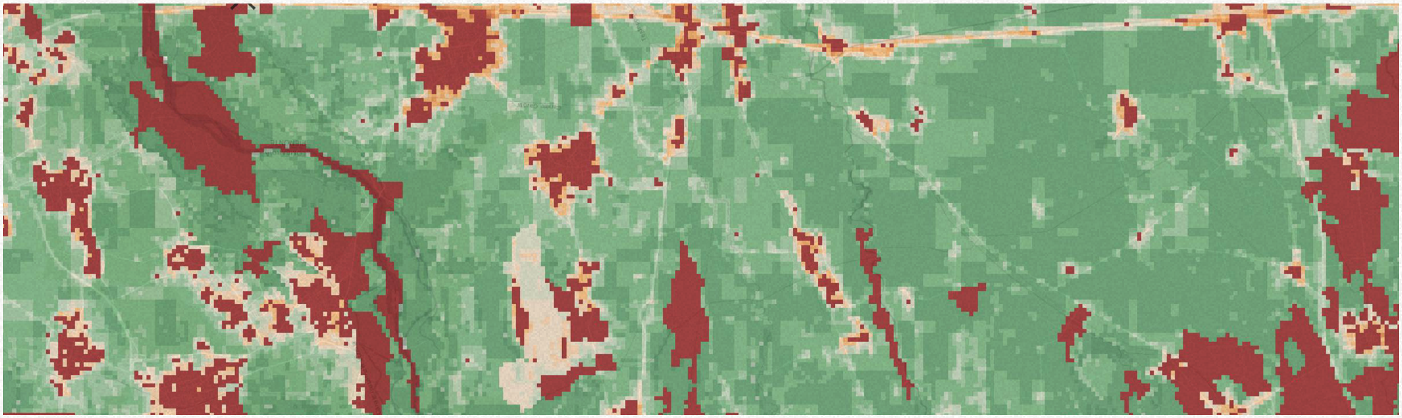
ECOLOGICAL RESISTANCE SURFACE

Currently, the most applied method in modelling (ecological) connectivity paths utilizes 'resistance surfaces' to reflect the influence landscape features have on organism movement (Zeller et al., 2012). The main attraction of this approach is its ability to be spatially explicit without requiring an extensive amount of parameters and input variables. The concept of resistance surfaces was initially introduced in the field of transportation geography in an attempt to quantify the influence of different landscapes on movement. The introduction of the ecological resistance surface model is a result of increased availability of high-quality geodata and increased use of GIS (Cushman & Huettmann, 2010; Wade et al., 2015).

A resistance surface is a raster map of the landscape, where each pixel is assigned a numerical value, reflecting the estimated 'cost of movement' through that pixel. The cost of movement is estimated or calculated by using various factors that can impede organism movement, e.g. vegetation density, slope, land cover, and building density. As the combination of these factors varies between places, this approach is point-specific. Resistance surface models exclusively describe the potential of the different spaces in a landscape to support organism movements and require other models or algorithms to identify explicit paths.

To be able to identify corridors or optimal travel paths, this approach is often applied in combination with other models, e.g., 'least-cost path' or 'minimal cumulative resistance' models (Adriaensen et al., 2003; Cushman & Huettmann, 2010). These computational algorithms utilize the values of the individual pixels to estimate the most favorable movement paths within a landscape (Cushman et al., 2013). In other words, they compute the route which poses the minimal cumulative resistance between two or more points. Although these models give insight in most favorable routing, there are serious limitations to these approaches in practice. Primarily, there is no reason to assume that organism knows (or thinks about) routes with minimum resistance. Besides that, there is no reason to assume that these organisms have a destination set when prior to movement (Webster et al., 2002).

Resistance surface models are of a temporary and static nature, ignoring the dynamism of a natural landscape. Seasonal rainfall and vegetation change often greatly alter animal movement and movement paths (Ingold, 1993), which is not accounted for in the resistance surface model. Furthermore, organisms themselves and animal movement paths are dynamic. Research has shown that migratory, diurnal, seasonal, an life-history cycles alter the way in which animals move through the landscape (Lorimer, 2015). These fluctuations are not reflected in these models.



EXAMPLE OF ECOLOGICAL SURFACE MODEL MAP IMAGE: OWN IMAGE

K-MEANS CLUSTERING

K-Means Clustering is an unsupervised machine learning algorithm designed to group unlabeled datasets into distinct clusters (Coates & Ng, 2012). Unsupervised learning involves training computers to process unlabeled and unclassified data, without human supervision, guidance, or predetermined categories or results. Unsupervised learning is perfectly suitable for uncovering hidden patterns in big data, that are not directly detectable when analyzed manually (Li et al., 2020). The goal is to group similar data points together. The mean values of the properties within such a cluster can inform on hidden patterns and categories within the dataset.

K-means clustering is a vector quantization technique with the objective to divide a set of ***n*** observations in ***k*** clusters. The properties of all data points are plotted and the distances between these points are used in clustering efforts. K-means is centroid-based, meaning that the distances between a point, and the centroids of established clusters determine to which cluster that data point belongs (Sinaga & Yang, 2020).

The number of clusters, K, is predetermined, and a clustering algorithm aims to group the data points into clusters such that the points in one cluster will be closer to the other points belonging to the same cluster than to points in another cluster. As a result, this will group the items based on the intrinsic similarities and differences among them.

K-Means analysis methods do this classification in the following way: First, the means, or cluster centroids, are initiated by making them random for each given k. Each point is then assigned to the closest mean point concerning distance, after which the mean's coordinates are recomputed as the average of the items in the group. This is repeated a fixed number of times to calculate the clearly defined clusters (Sinaga & Yang, 2020).

A common practical application of K-means clustering is customer segmentation in marketing (Chaturvedi et al., 1997). The technique is used by marketers to do a customer base analysis, identify the target areas, and segment customers based on the customer's behavior concerning past purchases, interests, or other variables. For instance, telecom providers can use K-means for analyzing customer behavior, on spending activity around recharges, SMS and internet usage, time spent calling, etc. Classifying their market supports the company in targeted campaigns for their different customer segments.

In spatial planning K-means clustering be applied in analyzing transportation and mobility trends, distribution of public services, classifying land-use, or identifying and managing urban sprawl.

CONVOLUTIONAL NEURAL NETWORKS & IMAGE CLASSIFICATION

Over recent years, neural networks and artificial intelligence have gained popularity in academic and practical fields, due to their ability to process and learn from large amounts of data. Technological advancements in terms of computational power, efficiency, and the availability of extensive datasets have further accelerated this trend (Steinkraus et al., 2005). Nowadays, NN are applied in a wide variety of practical applications, including image and speech recognition, natural language processing, autonomous driving, among others.

Neural Networks (NN) are a subset of machine learning algorithms that are inspired by the structures and functioning of the human brain. NN are interconnected layers of nodes that can process data through a series of weighted connections and activations functions. These networks are able to learn complex patterns and make predictions new data based on the input data it is trained on.

Image classification is one of the specific applications in computer vision. Image classification assigns a label to an image from a predefined set of categories. For instance, in an image classification task carried out to identify pictures of cats and dogs, the model predicts whether the picture contains a cat or a dog. Image classification using neural networks involves learning to identify image patterns or features. During training, the network will learn to adjust its weights from the provided labeled data. Over time, it will learn to recognize patterns within the correct labels, enabling it to make accurate predictions on new and previously unseen images.

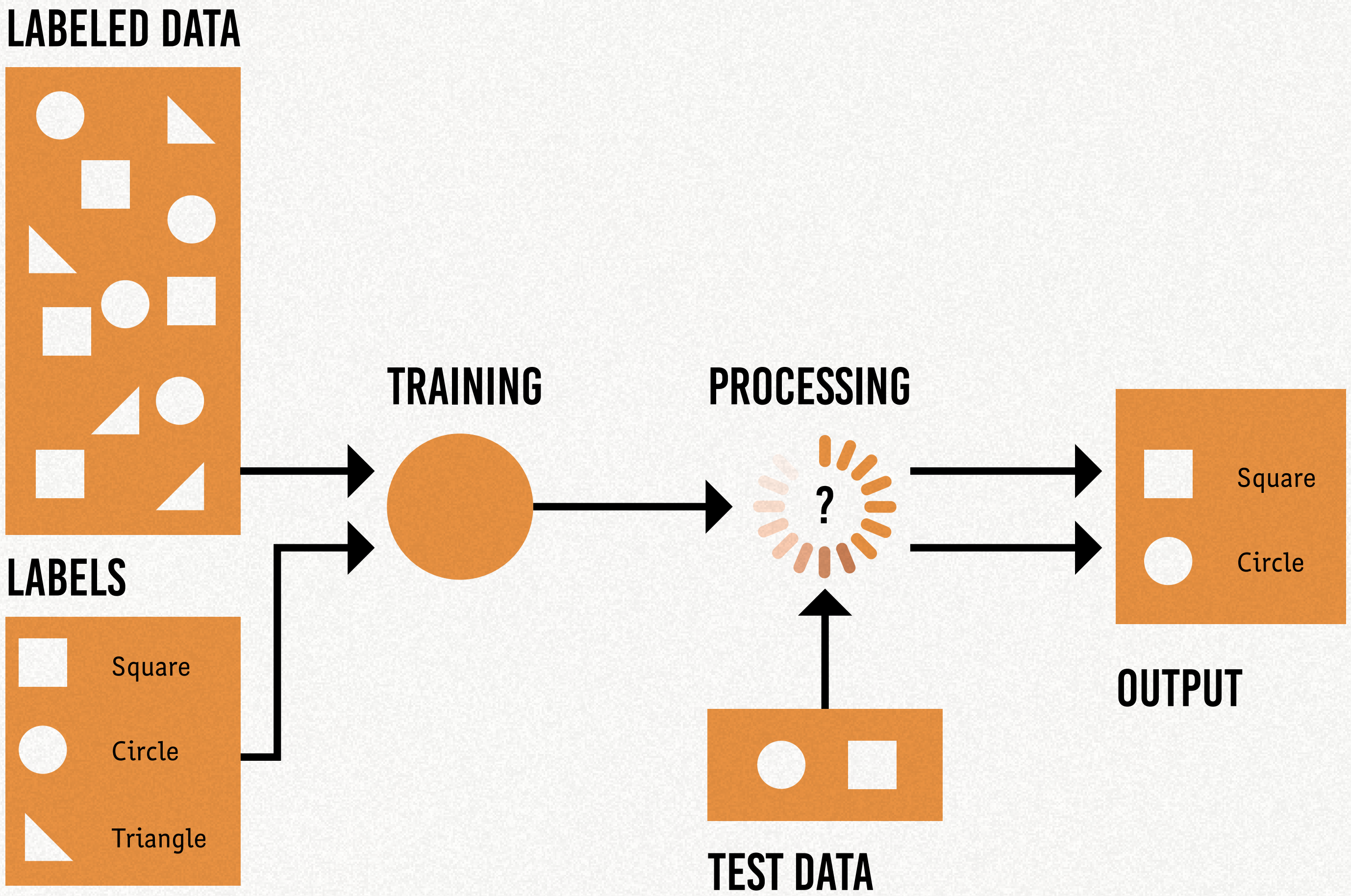
The structure, or architecture, of NNs are based on its functionality and differ between NN and the task it is designed to perform. For processing structured grid data, like images, a Convolutional Neural Network (CNN) is often applied. A CNN typically consists out of several convolutional and pooling layers, and fully connected layers (O'Shea & Nash, 2015). The convolutional layers apply filters to the input image to detect local patterns, like edges, textures, and shapes. The pooling layers downsample these maps, reducing their dimensions and enabling translations and variations to that input layer. After the processing the image, a fully connected layer operates like a traditional neural network, taking the flattened output from the previous layers and classifying the image into one of the predetermined category.

CNN are forms of supervised machine learning, needing large quantities of labeled and classified data to learn how and what to classify. Quantity and diversity within the training dataset is essential to create accurate and reliable results. The CNN is initialized with random weights for the individual neurons. By feeding the training data, the CNN calibrates these weights to come to the appropriate results. The training set is compiled of training, for training and improving classification results, and validation data to evaluate its performance during training.

Model training is conducted by feeding training data into a model, using a loss function that evaluates the difference between the estimated labels from the input features and the actual output and an optimizer that repeatedly updates the weight of the model to minimize the loss function (O'Shea & Nash, 2015). Performance on the validation set is monitored for the tuning of hyperparameters to prevent overfitting. The latter is a condition whereby the neural network has learned the training data too well and includes the noise and details that are specific to the training set, which yields poor generalization to new data (Basheer & Hajmeer, 2000). If trained properly, i.e., with high quantities of clean, controlled training data and the right amount of iterations, CNN can easily reach accuracies of 95-99% and is comparable to human vision accuracy(Russakovsky et al., 2015). However, data gathering and preparation tends to be challenging and time consuming.

CONCLUDING REMARKS

The presented theories form the foundation for the methods used throughout the thesis. Some of these theories are very targeted and specifically related to a certain spatial scale or challenges, whereas other theories present more generic principles and concepts. The next chapter further elaborates on how these theories are used within the design framework.



SCHEMATIC OVERVIEW OF THE IMAGE CLASSIFICATION PROCESS USING CONVOLUTIONAL NEURAL NETWORKS

IMAGE: OWN IMAGE

02

METHODS & MATERIALS

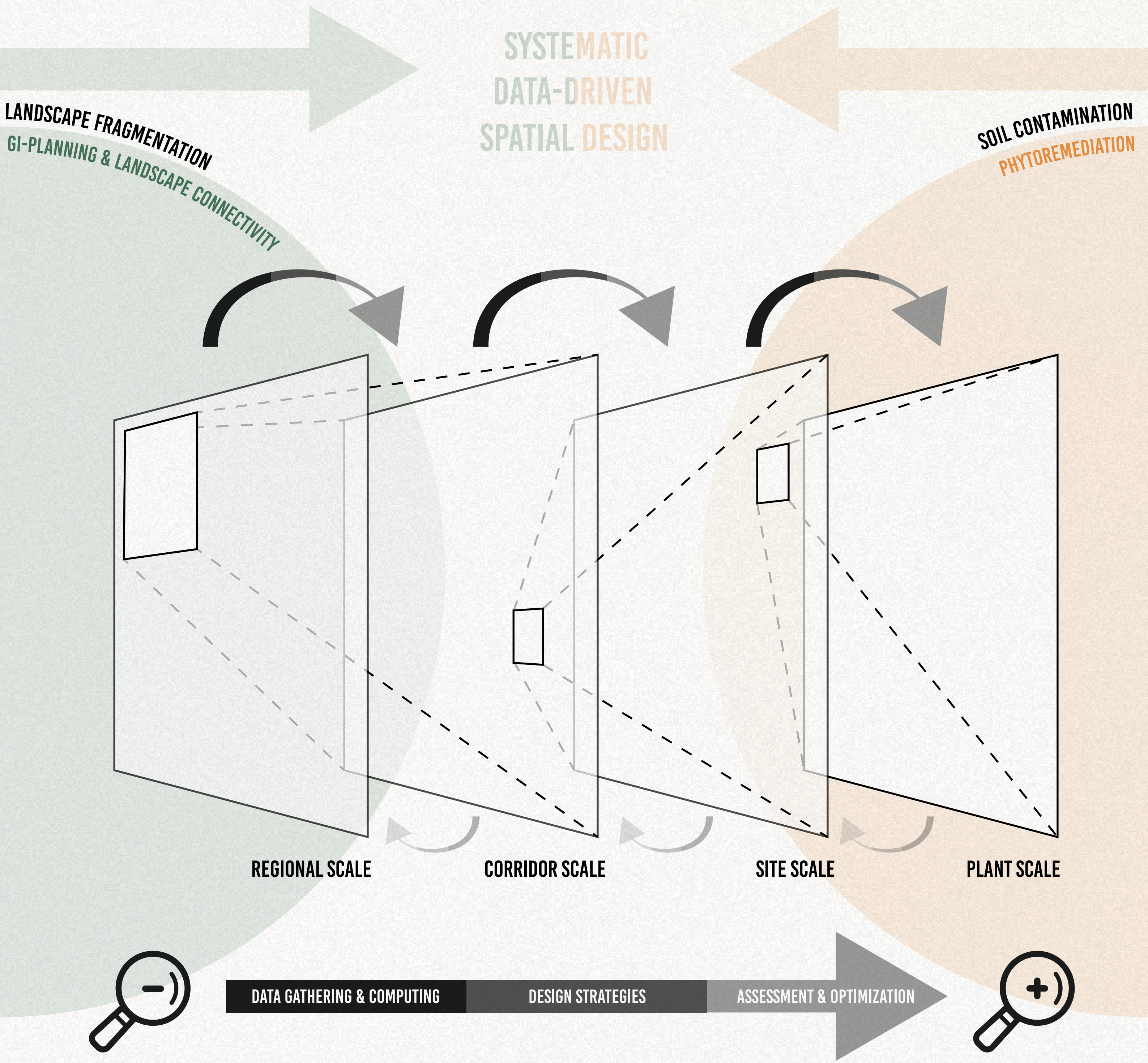
CONCEPTUAL FRAMEWORK

Environmental threats resulting from anthropogenic activities are becoming increasingly detrimental. This thesis focuses particularly on two critical environmental issues: landscape fragmentation and soil contamination. Landscape fragmentation is viewed as a regional-scale problem, disrupting ecological networks and threatening ecosystems. Excessive soil contamination, on the other hand, is often addressed more locally. Beyond preventing further environmental damage, it is crucial to restore already degraded ecosystems, preferably in sustainable and nature-based ways.

Sustainable tools and solutions for both the presented problems are already existing. GI-planning aims, among other goals, to combat landscape fragmentation and enhance ecosystem health, ES, and biodiversity. Concerning soil contamination, offers a nature-based solution to address soil contamination. Integrating both concepts into a holistic and integrated approach could significantly support and accelerate the implementation of these solutions.

To bridge the scalar gap between the phytoremediation a GI planning, a systematic framework is essential. It is crucial to systematically work across the different spatial scales and tackle the challenges that each of these scales presents, while providing flexibility and adaptability, to facilitate quick decision-making processes. Within the framework, all scales directly relate to each other but can be utilized and adapted individually.

The data-driven nature of this framework contributes to well-informed decision-making on all topics handled. The integration of data as both an analysis and assessment tool strengthens spatial claims and improves communication and collaboration among stakeholders and actors. By combining data analyses with design thinking, optimal solutions can be developed that build on the creativity and flexibility of design with the robustness and objective nature of data. By integrating data in analysis and assessment methods, all design decisions are based on and improved by the supporting data.


SYSTEMATIC
DATA-DRIVEN
SPATIAL DESIGN
LANDSCAPE FRAGMENTATION
GI-PLANNING & LANDSCAPE CONNECTIVITY
SOIL CONTAMINATION
PHYTOREMEDIATION
REGIONAL SCALE
CORRIDOR SCALE
SITE SCALE
PLANT SCALE
DATA GATHERING & COMPUTING
DESIGN STRATEGIES
ASSESSMENT & OPTIMIZATION

METHODOLOGICAL OVERVIEW

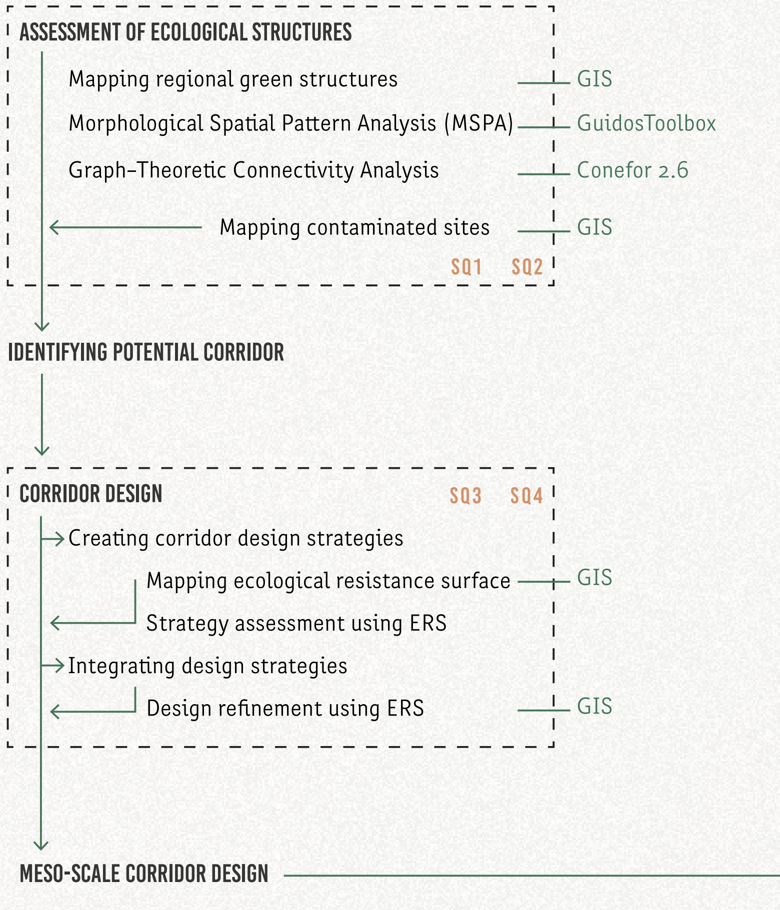
The methodology of this thesis can be divided into several individual steps. From the regional perspective, this includes the mapping of the landscape, focusing on both natural and ecological elements as well as contamination sinks and sources. Additionally, design strategies are developed to guide the implementation of the green corridor. From the local site perspective, a typology of contaminated sites is established, together with a pattern language of concrete design interventions and a database of appropriate vegetation.

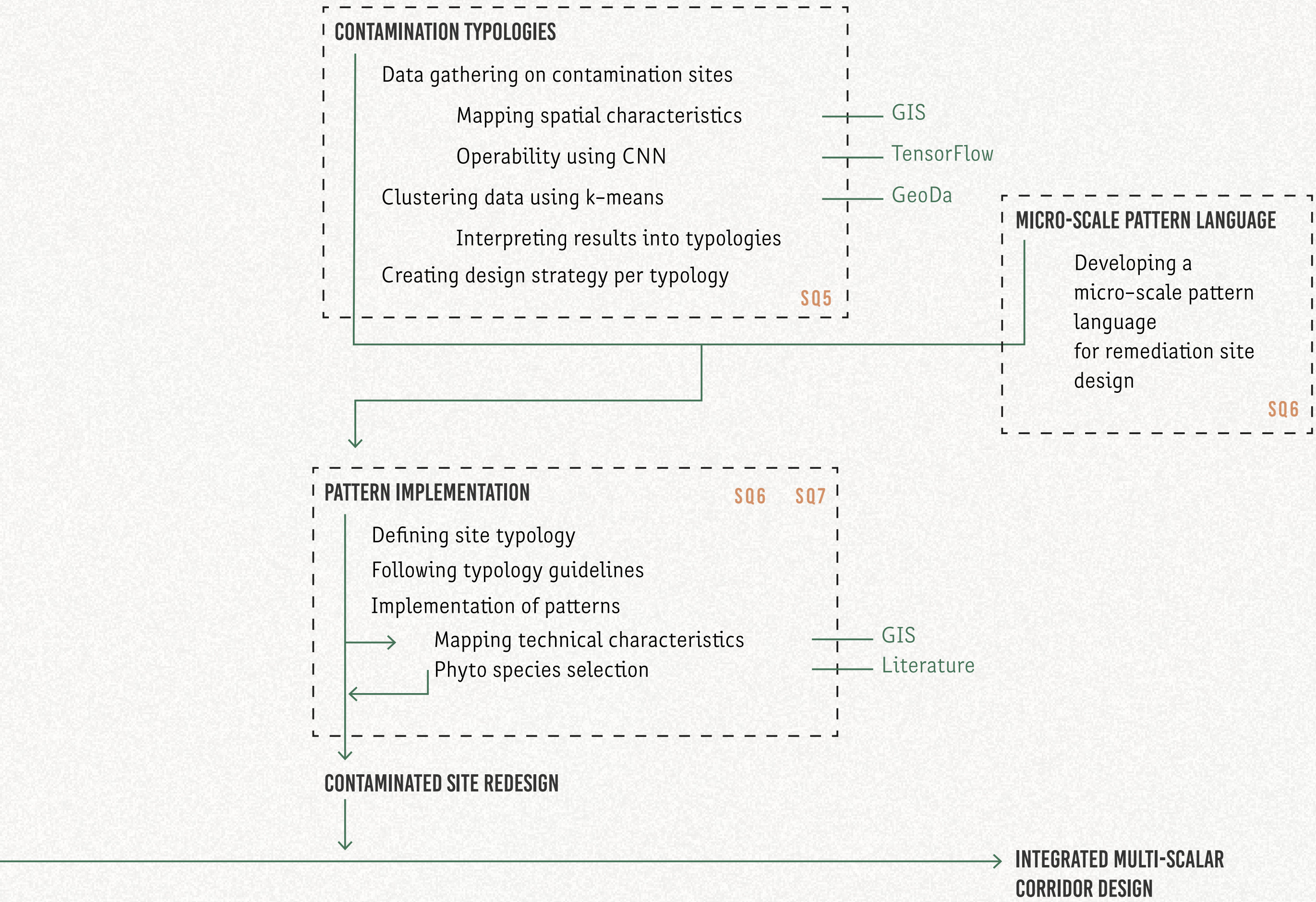
The current landscape structures are assessed using spatial data and various computational models. Firstly, the spatial patterns and landscape composition are assessed by conducting the MSPA method using GuidosToolBox. The identified structural elements are used for a quantified assessment of the ecological network connectivity using a graph-theoretic approach and the Conefor 2.6 software. The results present the contribution of the individual elements to the connectivity of the landscape. Potential new links are added to the calculations, leading to the identification of potential high-impact locations for GI-planning.

Once the location for the new GI is selected, it needs to be designed and fitted into the local context. To do this, multiple strategies are developed to guide the design process. Using the ERS model, the design options for the corridor paths are assessed and improved, leading to an optimized design proposal.

From the local perspective, the contaminated sites within the corridor area are segmented into a typology. These typologies can be used to create targeted design strategies that fit the properties of the contaminated sites. Using spatial data and the GeoDa software package, a k-means clustering results in the proposed typologies.

A pattern language is developed that focuses on micro-scale design interventions incorporating phytoremediating and socio-economic opportunities. The proposed design patterns are implemented in two selected contaminated sites that are used as showcase sites for implementing phytoremediation in contaminated locations. A database of phytoremediation vegetation is developed based on a literature review. The same showcase sites are used for the implementation of this database.




CONTAMINATION TYPOLOGIES
Data gathering on contamination sites
Mapping spatial characteristics
Operability using CNN
Clustering data using k-means
Interpreting results into typologies
Creating design strategy per typology
SQ5
GIS
TensorFlow
GeoDa
MICRO-SCALE PATTERN LANGUAGE
Developing a micro-scale pattern language for remediation site design
SQ6
PATTERN IMPLEMENTATION
SQ6
SQ7
Defining site typology
Following typology guidelines
Implementation of patterns
Mapping technical characteristics
Phyto species selection
GIS
Literature
CONTAMINATED SITE REDESIGN
INTEGRATED MULTI-SCALAR CORRIDOR DESIGN

REGIONAL SCALE I - ECOLOGICAL STRUCTURES

WHAT ARE THE COMPONENTS OF THE CURRENT NATURAL LANDSCAPE STRUCTURE, AND HOW CAN THEY BE ENHANCED?

OBJECTIVES

The first research question aims to assess the current natural landscape and focuses on the identification and classification of various structural landscape components. Traditional mapping of the study area contributes to an improved understanding of the landscape. More in-depth analysis of the natural landscape elements and their landscape structures is crucial for effective GI planning, as it allows for the identification of potentially important areas for designing enhanced landscape connectivity.

The landscape structure assessment is performed using an MSPA. This is a quantitative approach that involves the categorization and quantification of the landscape elements based on binary raster data. Spatial data on land cover types, land use, vegetation, and water bodies is used to create an overview of the natural landscape. Based on their shape and composition, the individual elements are classified into landscape classes conform to the MSPA landscape classification.

DATA GATHERING & PREPARATION

To conduct the assessment QGIS 3.32.3 and GuidosToolBox are used. MSPA requires a binary raster input. QGIS is used for data preparation and processing of this binary image. The data is gathered from the Copernicus Land Monitoring Service, specifically the Corine Land Cover (CLC) dataset from 2018. Recent satellite imagery is used for the validation of this mapping. The CLC dataset includes 44 land cover types distributed across five main categories. These categories are not based on ecological values, so a new classification of land cover types relevant to the ecological landscape needs to be created. For this analysis the following land cover classes are used:

CLC-classes considered as ecologically relevant:

- 2.4.1 Annual crops associated with permanent crops
- 2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation
- 2.4.4 Agro-forestry areas
- 3.1.1 Broad-leaved forest
- 3.1.2 Coniferous forest
- 3.1.3 Mixed forest
- 3.2.2 Moors and heathland
- 3.2.3 Sclerophyllous vegetation
- 3.2.4 Transitional woodland-shrub
- 4.1.1 Inland marshes
- 4.1.2 Peat bogs
- 4.2.3 Intertidal flats
- 5.1.1 Water courses
- 5.1.2 Water bodies
- 5.2.1 Coastal lagoons
- 5.2.2 Estuaries
- 5.2.3 Sea and ocean

METHODS

The data preparation is performed in the GIS environment of GQIS. The selected categories from the CLC 2018 are isolated and compiled into one binary raster image. This image is of a byte data type, where the selected natural landscape features carry a positive value (1) and the surrounding landscape has a negative value (0). The binary map layer has a resolution of 25m x 25m.

GuidosToolBox is used to conduct an MSPA. Based on literature and prior research, an 8-neighborhood in combination with an edge width of 2px, resembling 50m on scale. The MSPA results include a spatial map showing the distribution of the individual structural elements, as well as a table containing quantitative data on the counts and ratios of the individual component classes.

The MSPA results are interpreted to identify areas with high concentrations of islets, branches, and isolated ecological cores. These areas are selected for further research on landscape connectivity.

EVALUATION

The assessment is based on the CLC 2018 dataset, which carries a lot of information but has a limited spatial resolution. While using regional land cover and spatial planning data would provide more detailed, accurate, and recent spatial information, computational constraints limit the practical useability of such datasets, especially on this scale. For smaller scale assessments, regional datasets, like the BDTRE: The Territorial Reference Database of Piedmontese Bodies from the Piedmont Regional geodatabase in this case, would result in more accurate results. For this regional assessment, the CLC dataset is considered sufficiently accurate.

REGIONAL SCALE II - LANDSCAPE CONNECTIVITY

WHERE WOULD A NEW GREEN CORRIDOR MOST EFFECTIVELY ENHANCE LANDSCAPE CONNECTIVITY?

OBJECTIVES

The prior research question has led to an assessment of the landscape structure and the identification of the individual structural components. To optimize this structure, it is crucial to quantify the connectivity of this landscape. Each component, and connection, contributes to the connectivity of the landscape. This approach calculates and quantifies that contribution allowing for comparison between the individual components. Critical connections in the current landscape are identified and the potential positive impact of new connections is assessed. By quantifying connectivity, the optimal location for a new green corridor can be determined based on its impact on landscape connectivity and the presence of soil-contaminated sites. This optimal location is used in further stages of the project for implementing the corridor design.

DATA PROCESSING

This methodology uses the Conefor 2.6 software package to determine the network connectivity. This tool requires graph-network data as input. This input data consists of two files: one node-file; containing all ecological core areas with an ID-value and the area size, and one connection-file; containing all connections between the cores, consisting of the two corresponding node-IDs and the distance between them. The ecological cores are derived from the MSPA and processed with QGIS to add the corresponding area size. The connection distances are calculated from edge to edge using ArcGIS and the Conefor-plugin. To minimize computational issues, a maximum threshold distance of 30 kilometers between the core edges is maintained.

The quantification of connectivity is done using probabilistic metrics. This requires values for average dispersal distances of the studied wildlife. As this study does not focus on specific species, but on ecosystems in general, the common honeybee (Apis mellifera L.) is used as a representative pollinator species. An average dispersal distance of 865 meters, derived from the literature, is used as input data for probabilistic connectivity.

METHODS

The prepared data files, containing information on the ecological core and their connections are used as input for the network connectivity analysis in Conefor 2.6. First, an assessment of the connectivity of the current landscape is performed. The average dispersal distance from the common Honeybee is used in combination with a probability of 0.5, based on prior research and scientific literature on landscape connectivity and wildlife studies. The analysis results are visualized spatially using QGIS.

Additionally, a Link Improvement calculation is conducted to estimate the impact of strengthened or added connections in the existing landscape. Due to the large extent of the dataset, a maximum distance of 15 kilometers is used for these added links. For this analysis, the same probabilistic input data is used as in the prior calculations. Results from this calculation are again visualized spatially using QGIS. The dPC-connector values serve as an index for connectivity impact.

The results from both connectivity studies are mapped and analyzed. To identify the optimal potential corridors, the links with the highest connectivity impact values are selected. As the design approach is aimed at integrating phytoremediation and contaminated sites in regional GI planning, the optimal corridor location consists of a combination of contaminated sites and potential links with high dPC-connector values.

EVALUATION

This approach employs robust, unambiguous, and well-defined connectivity metrics. Quantifying connectivity using graph network theory allows for comparison between potential locations, resulting in well-informed decisions. The ability to visualize this impact using GIS software enables accessible analyses and comparison with other spatial components, including the spatial distribution of contaminated sites. However, this approach is based on estimated species movement and uses Euclidean distances between ecological cores, which may not accurately reflect actual animal movement patterns and functional distances. Additionally, using the honeybee as a representative species has limitations, as dispersal distances between honeybee colonies can vary significantly, and biodiversity is supported by more species than just honeybees. Tracking actual animal movements and incorporating multiple species in the analysis could further improve the accuracy of this assessment.

CORRIDOR SCALE I - DESIGN STRATEGIES

WHAT STRATEGIES CAN BE USED TO DESIGN THE GREEN CORRIDOR PATH BASED ON SPATIAL STRUCTURE?

OBJECTIVES

The first two research questions focus on the regional scale and have led to selecting the location of a new green corridor within the regional landscape. This research question is focused on the design, implementation, and effectiveness assessment of the corridor on a smaller scale. To design this corridor effectively, strategies and guidelines are developed to integrate the corridor with the existing landscape. The strategies aim to facilitate efficient and effective design processes for the corridor path. The designed options can be assessed and evaluated during the next research question.

DATA PROCESSING

The creation of design strategies is based on both quantitative and qualitative data. Initially, the selected corridor location is detailed mapped against important spatial structures, including watercourses, major infrastructure, agricultural parcels, industrial areas, and natural landscape patches. Regional and local spatial data is used for this mapping processing, primarily gathered from the Piedmont Geoportal. To establish the design strategies, best practice projects and literature on GI design are used as a foundation.

METHODS

Using the gathered datasets from the Piedmont regional geoportal and the municipality of Novara, the spatial structures of the corridor area are mapped in QGIS. The contaminated sites are included in this mapping as well.

Four distinct design strategies are developed, each pursuing different ecological goals and aligning with varying spatial structures. The strategies are implemented and fitted in the corridor location. Depending on the specific context, not all of these strategies are feasible. Multiple design options for the corridor path are created using the design strategies. These strategies are assessed in the following research question.

EVALUATION

The development of the multiple design strategies contributes to the systematic approach that is pursued during the thesis. Adaptations to the strategies can be made to fit other contexts, without the need to adapt the entire design procedure. Additionally, the strategies allow for the creation of quick design options, creating a reproducible and efficient workflow. However, it is essential to note that these strategies only serve as a starting point and they should be effectively fitted to their specific context.

CORRIDOR SCALE II - ASSESSING DESIGN STRATEGIES

WHICH DESIGN STRATEGIES ARE MOST EFFECTIVE BASED ON ECOLOGICAL MOVEMENT POTENTIAL?

OBJECTIVES

The previous sub-question results in a variety of design options for the corridor path. To make well-informed decisions during the design process, these design options are assessed on the ability to facilitate ecological flows and species movement. By quantifying the ecological resistance, this method helps in selecting optimal design solutions and combining the different options to create integrated optimized solutions. By using the ERS model, the landscape is analyzed and mapped on ecological resistance, based on both human and natural factors, enabling the quantification of resistance. As this method is spatially explicit, the results do not only calculate resistance values but also identify specific high-resistance locations, which can be addressed during the design phase.

DATA PROCESSING

The ERS model consists of various layers of resistance factors. Based on literature research, the following resistance factors are selected: vegetation density, land cover type, building density, and road density. Given the relatively flat study area, the slope is excluded as a resistance factor. For vegetation and building density, the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-Up Index (NDBI) are used, gathered from the Copernicus Land Monitoring Service. Land cover types are derived from the Corine Land Cover (CLC) 2018 dataset, and road density is calculated using OpenStreetMap and QGIS. QGIS is used to compile the integrated ERS, with the 'Profiles from Lines' plugin from SAGA used to calculate the ecological resistance for the individual corridor paths.

METHODS

First, the gathered spatial data on resistance factors are processed in QGIS. All layers are normalized for the study area and have values ranging from 1 (low resistance) to 5 (high resistance). The individual resistance factors are compiled into one integrated ERS using the raster calculator QGIS.

The corridor design options from the previous chapter are then assessed using the ERS and the 'Pro-files from Lines' plugin. This plugin samples the resistance encountered by these paths at set interval distances. The resulting cumulative and mean values for the design options are compared and used to select the optimal option. As the best strategy option may differ along the corridor, the optimal corridor is a combination of all the strategies. The resistance is visualized in GIS and, based on this spatially explicit data, an integrated design is developed that incorporates the best components of the individual assessed design options.

The integrated corridor design is subsequently assessed using the ERS model. A well-designed corridor path should present a lower average and similar, or lower, cumulative resistance values in comparison to the prior design options. The calculations also highlight the remaining bottlenecks in the designed corridor. These locations need to be specially addressed during design and planning to create a coherent and efficient green corridor. As a final step, the optimized corridor path is detailed and structured in a coherent structure of landscape components, including forests, riparian zones, and linear green patches.

EVALUATION

The proposed methodology to assess the different corridor path design options combines design thinking and computational calculations to arrive at optimized solutions. The use of design thinking in the creation of individual options allows for creativity and flexibility, while the ERS model provides concrete and unambiguous data to support design decisions. However, the use of the ERS model comes with severe limitations. The ERS is composed of different resistance factors. The impact of these factors is not evaluated or researched, resulting in equal weights in the calculations. In reality, one factor may contribute stronger to ecological resistance than others. Besides correlations between the individual factors are not addressed and no statistical tests have been performed. Additionally, wildlife movement does not always follow the path of least resistance, and landscapes can be dynamic and change seasonally, affecting migratory routes and movement paths. Furthermore, the ERS model focuses solely on wildlife movement potential, whereas green infrastructure aims to support multiple ecosystem services and cannot be assessed on a single component alone.

SITE SCALE I - TYPES CONTAMINATED SITES

WHAT TYPES OF CONTAMINATED SITES EXIST WITHIN THE STUDY AREA?

OBJECTIVES

Understanding the spatial configurations and (technical) properties of contaminated sites is essential for developing targeted and efficient phytoremediation strategies. Since the contaminants, their concentrations, and sources vary significantly between the sites, so do their spatial configurations. To create a better understanding of these contaminated sites, their locations and characteristics are mapped. Identifying patterns in the mapped data allows for classifying and categorizing contaminated sites, which can be expanded with targeted design solutions, tailored to the specific needs and potentials of each site category.

DATA PROCESSING

A k-means clustering analysis is performed to establish the typology of contaminated sites. This clustering is purely based on the spatial properties of the sites, including site area, (surrounding) primary land use, the presence of buildings or other structures, and the operability state of the site. Data mapping and preparation are conducted in QGIS.

The location of contaminated sites is gathered from the Anagrafe di Siti Contaminati (ASCO) dataset from the Piedmont region. Cadastral data is used to determine the boundaries and site area. The study includes 171 sites, all located within a 25-kilometer radius of the corridor area. The primary land use is determined using the CLC 2018 dataset, gathered from the Copernicus Land Monitoring Services. To determine the operability of the site, Google Street View Imagery is reviewed which is gathered using the Google Maps Static API for Python. A CNN trained on image classification of active and inactive buildings is used to classify the sites within the study area. This CNN is created in Python using the TensorFlow library and is trained with Google Street View imagery of 4,340 abandoned Dutch buildings, whose locations are sourced from the Basisregistratie Adressen en Gebouwen (BAG) dataset from the Dutch Cadaster.

METHODS

Using QGIS, the spatial properties of the contaminated sites are mapped using the gathered data. Since the operability state is not directly available as a dataset, the coordinates of the buildings are sampled. Using the Google Maps Static API and Python, site imagery is downloaded based on the sampled coordinates. The CNN classifies the state of the sites based on the images and stores the results in the geodatabase.

The CNN is trained on imagery of Dutch cases of inoperable buildings. The training data is gathered using a similar approach: the coordinates of inoperable buildings are sampled, after which the Google Maps Static API is used to gather the imagery.

With the geodatabase complete, a k-means clustering is performed in GeoDa 1.22. The elbow method indicates an optimal k-value of 5, ensuring distinct and meaningful typologies, without excessive differences. Due to time constraints, all values are weighted equally in the clustering.

The clustering results are interpreted and used for the establishment of the contaminated site types. Each type within the typology is described and general design guidelines are proposed to support further design activities.

EVALUATION

The methodology provides a systematic, structured, and reproducible approach for identifying and classifying the contaminated sites. By using k-means clustering, it is ensured that the sites are categorized on natural groupings within the spatial data. As k-means clustering is an unsupervised method, it allows for the uncovering of patterns that are not initiated by predefined categories or labels. The option of creating typologies based on spatial features, allows for a more nuanced understanding of the contaminated sites, without the need to investigate them individually.

The created typologies enable the use of standardized design strategies that are still effective and targeted to the characteristics of these sites. This optimizes resource allocation and allows for more efficient redevelopment processes.

However, the data used for the typology creation is limited. Including more attributes, could result in more detailed typologies. Simultaneously, this could result in the need for more typologies, as the characteristics of the contaminated sites differ a lot.

The CNN used for the operability assessment of the sites has an accuracy of merely 70%. This results in false data during clustering. Besides, the CNN is trained on data outside of the study area. Differences in culture, landscape, climate, etc. between the training and study data, can result in false assessment of contaminated sites. Additionally, the Google Street View imagery is often outdated or insufficient for determining actual operability.

Apart from the CNN, inaccuracies in plot sizes exist, particularly for contaminated sites in public space, as these often do not fall within defined cadastral plots. Manual mapping of the sites is not viable due to the large amount of contaminated sites in the area. Therefore, this data-gathering approach using machine learning and digital mapping is used. Using more accurate, up-to-date, and detailed data could enhance the validity and accuracy of the clustering. Adding more criteria to the clustering method, including contamination types, and concentrations can be interesting, however, this data is often missing. Despite these limitations, this approach still is viable and enhances the understanding of the contaminated sites and improves the efficiency of environmental redesign practices.

SITE SCALE II - CONTAMINATED SITES REDESIGN

WHAT DESIGN PATTERNS CAN BE APPLIED TO THE REDESIGN OF CONTAMINATED SITES?

OBJECTIVES

The sixth sub-question aims to identify and establish spatial design patterns that can be used for the redesign of contaminated sites. The focus lies on integrating phytoremediation practices with socio-economic program. This is done without specifying the exact vegetation types and species, as these can be fitted to the specific contamination types and concentrations during the implementation. The patterns provide a framework for replicable and scalable design interventions that can be applied across multiple contaminated sites and align with the design guidelines for the site typology.

DATA PROCESSING

The creation of the pattern language is based on best-practice cases, literature reviews, and design explorations. Reference cases are gathered through online reviews and analysis of successful projects that have implemented similar strategies.

METHODS

The design patterns are developed and tested using two contaminated sites in the area as test cases. Using a combination of explorative design and reference projects, generalized design patterns are created. These patterns vary from primarily remediating program, with little socio-economic significance, to ones that focus primarily on socio-economic opportunities and only slightly contribute to soil remediation.

Each pattern is documented within a pattern template, showcasing the requirements and opportunities of the pattern. This includes spatial and programmatic requirements, requirements on vegetation types, phasing, and complementary remediation strategy.

EVALUATION

The use of a pattern language contributes to the systematic and organized nature of the entire thesis project. The pattern language ensures consistency, coherence, and efficiency across the different contaminated sites. Additionally, it facilitates quick design explorations that are flexible and be adapted, changed, or expanded, depending on the project-specific needs, leading to targeted and tailored design solutions.

Additionally, the pattern language enhances communication between stakeholders and provides an accessible framework for design explorations. It integrates within the overall design approach for green infrastructure (GI) planning and phytoremediation, establishing a systemic framework that allows for adaptations on individual scales without disrupting the entire framework, thereby maintaining flexibility.

Although the pattern language aims to enhance and facilitate communication and design processes, it can be limiting in some conditions. It is important to remain open to innovative thinking and creative solutions beyond the established patterns and note that the proposed pattern language is open-ended. Additionally, the implementation and fitting of these patterns may be more complex than anticipated, requiring extensive evaluation and assessment to ensure their effectiveness.

PLANT SCALE - VEGETATION SELECTION

WHICH PLANT SPECIES ARE SUITABLE FOR THE SELECTED DESIGN PATTERNS AND SITE-SPECIFIC CONDITIONS TO EFFECTIVELY REMEDIATE THE LOCAL SOIL?

OBJECTIVES

The last step of the redesign process concerns the selection of phytoremediating vegetation that fits the site-specific contamination, contaminant concentration, soil characteristics, and the introduced program. These criteria vary widely between contaminated sites, requiring a thorough examination of the location before implementing appropriate remediation interventions. The selected vegetation must fit the local climate and contamination characteristics for them to be effective in remediating the soil and enhancing the local GI. This sub-question results in an overview of phytoremediating vegetation, an overview of relevant site-specific properties, and a decision-support tool for selecting the appropriate vegetation for the sites, all aiming to support the decision-making process of phytoremediating vegetation.

DATA PROCESSING

To determine the appropriate plant species, several types of data are required. Firstly, the contami-nated sites have to be mapped on soil type, soil pH, local climate, groundwater conditions, and con-taminant types and concentrations. The Information data on soil types and pH values are gathered through the database of ISRIC- World Soil. Spatial data on climate, temperatures, and soil moisture are gathered from the Copernicus Land Monitoring Service. As (spatial) data on contamination and contaminant concentration is lacking in regional datasets, assumptions on the site level are based on former and current on-site practices.

Data on the phytoremediating capabilities of various types of vegetation is gathered from scientific literature, with 'Phyto' (Kennen and Kirkwood, 2015) and the 'Famulari Phytoremediation Database' (Famulari, N.D.) as primary sources. Further data on the used vegetation, like soil and climate prefer-ences, as well as growth habits, is gathered using online databases.

METHODS

This approach is based on assumptions of present contaminants and contaminant concentrations. For this approach to be used in practice, gathering more accurate and detailed information on the contamination is essential, e.g. by using soil samples. Additionally, the concentrations and dispersion of the contamination can differ between locations within the site itself, which is not accounted for in this approach. Data on the phytoremediating capabilities of the vegetation is still in development and often happens in controlled laboratory studies, which are not always representative of practical implementations.

To improve this methodology, more accurate and advanced data collection techniques should be incorporated. This includes soil samples and thorough assessment before the redesign practices, but also field validation and studies to validate the effectiveness of these plants in practical situations.

However, the systematic nature of this approach offers well-informed decisions on the selected vegetation. The accessibility of the approach allows for easier communication between planners, designers, botanists, and local stakeholders. The decision support tool further decomplicates the plant selection process and aids in creating more thriving and effective phytoremediation practices. However, all decisions on vegetation types should be validated by experts.

EVALUATION

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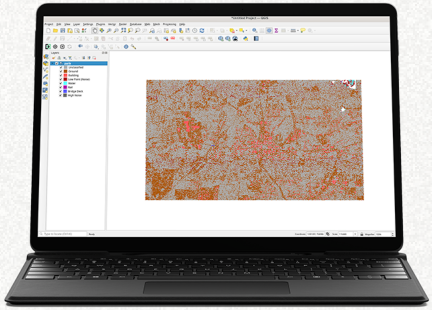
TOOLS & SOFTWARE

The data-driven nature of the method presented in this thesis requires the processing of large amounts and various types of data. Various models and software are used in the process of data collection, processing, interpretation, and modeling. The following pages provide a brief overview of the programs used.

The use of open and accessible data and software is of paramount importance, resulting in the decision to exclusively use open-source software in the design methodology.

QGIS

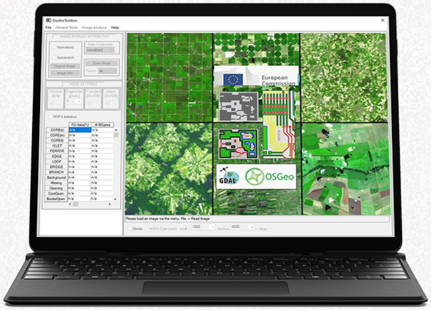


DESCRIPTION & APPLICATION

QGIS is an open-source Geographical Information System (GIS). The software allows users to visualize, analyze, and edit spatial data. The use of plugins and Python scripts extends the capabilities of QGIS even further.

In this thesis, QGIS is used to process the spatial data. Multiple plugins were used for the processing of spatial data.

GUIDOSTOOLBOX (GTB)



DESCRIPTION & APPLICATION

GuidosToolbox (Graphical User Interface for the Description of Image Objects and Their Shapes - GTB) is a remote-sensing software focused on geometric analysis tools using raster images. In this thesis, GTB is used for performing Morphological Spatial Pattern Analyses (MSPA) to classify and categorize different structural elements within the green network. GTBs MSPA forms the basis for the network connectivity analyses.

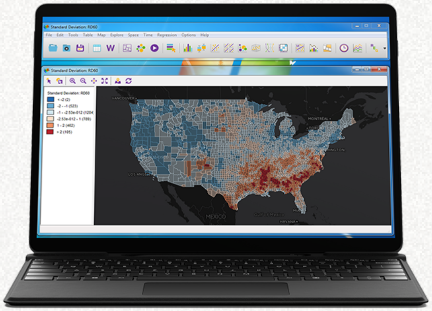
CONEFOR 2.6

DESCRIPTION & APPLLICATION

Conefor 2.6 is a software package for quantifying the importance of habitat areas in terms of size and connectivity. The software implements a graph-theoretic approach to determine the extent of connectivity.

Conefor 2.6 is used as a decision-making support tool for landscape conservation planning and spatial ecology analyses. In this thesis, Conefor 2.6 is used to identify the most crucial elements of the green structure in the current situation and to assess the connectivity potential of proposed links in the green network.

GEODA 1.22

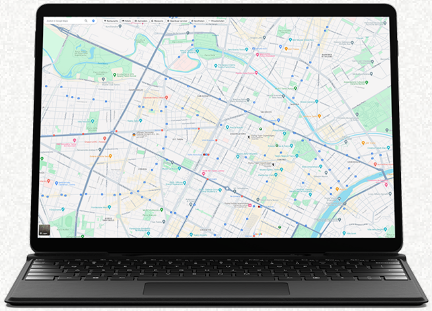


DESCRIPTION & USE

GeoDa is a free and open-source software tool for exploratory spatial data analysis (ESDA). GeoDa is widely used in geospatial data exploration and allows quick and user-friendly statistical analysis and visual presentation. GeoDa is very useful in finding statistically significant spatial clusters.

In this thesis, the k-means clustering function from GeoDa is used to identify statistically argued clusters and typologies, that allow for strategy-making and targeted spatial design based on local parameters.

GOOGLE MAPS STATIC API



DESCRIPTION & USE

Google Street View imagery offers spatial designers a tool for understanding the built environment and its direct context remotely. The on-the-ground perspectives allow visual interpretation of the site to extend the knowledge and grip on the site. Google Street View Static API allows viewing and downloading static images from Google Street View using the coordinates of the place. The API makes it easy to quickly gather visual data on a large set of sites without the need for physical visits, or manually using Google Street View. The API is used for quickly gathering visual information on contaminated sites in the area, which is used for determining the state of operability of the selected sites.

TENSORFLOW

DESCRIPTION & USE

Artificial Intelligence and Neural Networks are getting more and more common. Being able to automate repetitive tasks improves efficiency in data gathering. Being able to quickly assess large quantities of data points, not only accelerates the research process, but also allows for increasing sample sizes, and therefore getting more accurate and extensive results.

TensorFlow is an open-source software library used in machine learning and artificial intelligence. The library can be used for a wide variety of machine-learning applications, including image recognition, text processing, audio recognition, and many more. For this thesis, the Tensorflow library is used in combination with Python for object detection in imagery. Using imagery gathered with the Google Maps Static API, the neural network is trained to recognize images and classify them as either actively used or inactive. This data is later used in combination with other spatial data on these locations for statistical clustering and the identification of typologies within sites.

03

REGIONAL ASSESSMENT

SPATIAL COMPOSITION - REGIONAL MAPPING

ASSESSING THE ECOLOGICAL STATE

MAPPING LAND COVER TYPES

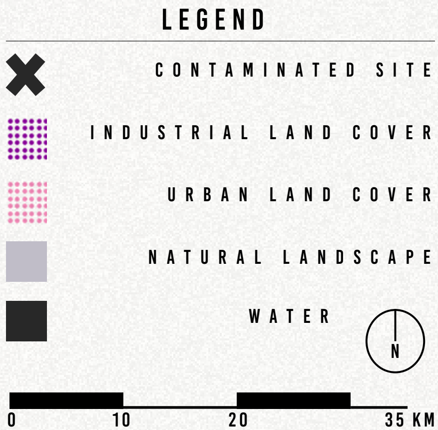
Before jumping into computational analyses of the natural landscape, a basic understanding of the spatial configuration is needed. Using data provided by the administrative region of Piedmont, OpenStreetMap, and the Corine Land Cover, a map is made showing the major land cover types, natural structures, urban and industrial centers, and ground elevation. The mountainous areas along the regional boundaries are far less altered by human activities and host a lot more natural functions in comparison to the valley. The plain primarily hosts agricultural land use, where large continuous agricultural landscapes keep the natural elements apart. Industrial areas are clustered in larger industrial zones, primarily around urban cores and/or along major transport infrastructure. The urban land cover is more dispersed than the industrial zones, resulting in a lot of relatively small settlements within the valley plain. Most urban centers, including those of Turin, Vercelli, Novara, and Chivasso are located along the riverbeds. As the riverbeds are also one of the rare areas for natural land cover, these urban environments, and their accompanying infrastructure are actively contributing to landscape fragmentation.

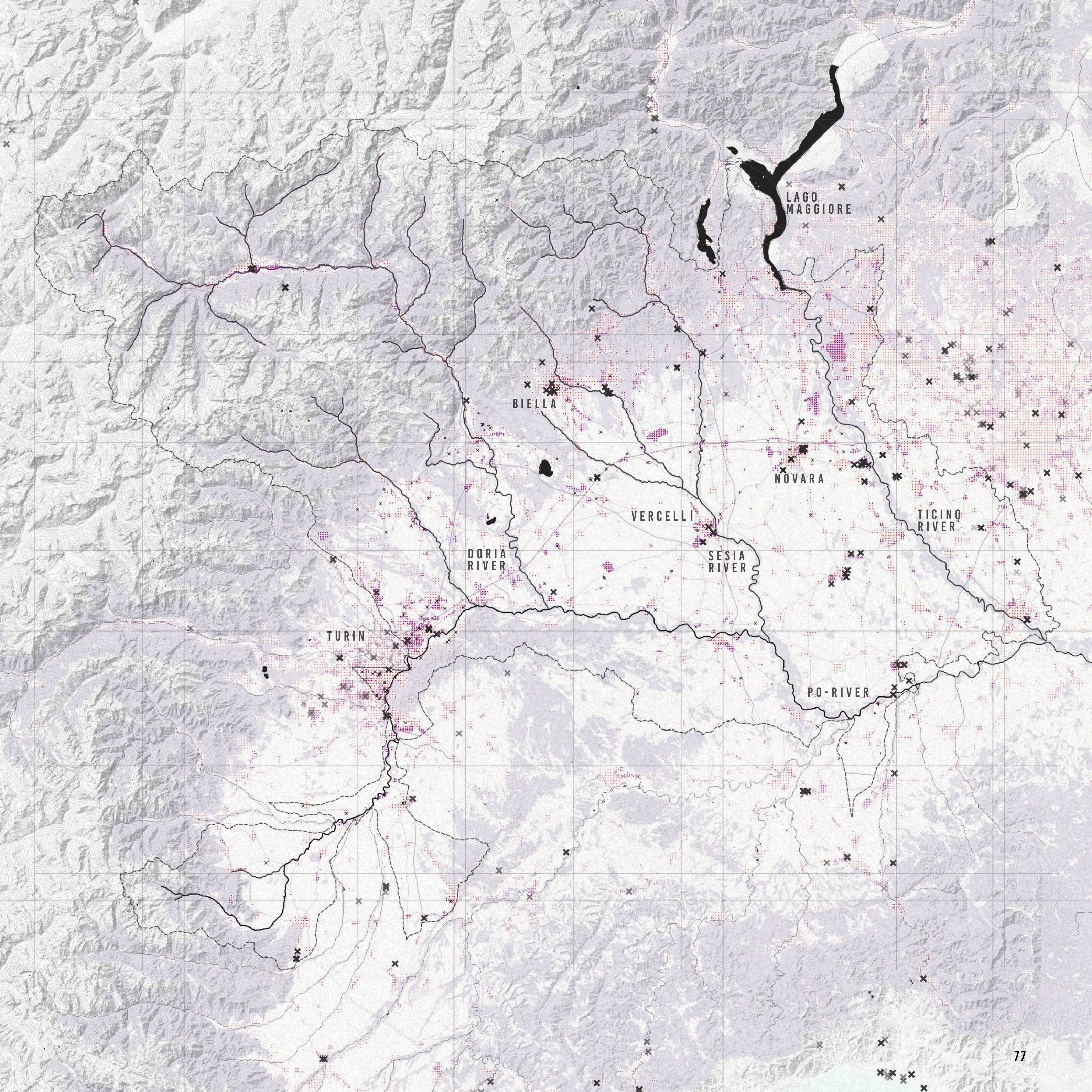
IDENTIFYING CONTAMINATION HOTSPOTS

Using data from the European Pollutant Release and Transfer Register (E-PRTR) and regional data from the Piedmont region in collaboration with the ISPRA, sites that suffer from soil contamination are mapped. This includes sites that are still operable and actively polluting the environment, as well as areas that are closed due to contamination. When analyzing the spatial distribution of these sites, concentrated occurrences can be found in proximity to major urban cores, such as Turin, Milan, Novara, and Biella. This highlights the relationship between anthropogenic activities and contamination. The fact that most of the contaminated sites are in more urbanized areas, means that when integrating phytoremediation strategies into GI design the proposed corridors have to route through the urban areas. As these areas are more dense and pose higher resistance to ecological integration in comparison to rural areas this makes designing green infrastructure a bit more challenging.

NAVIGATING THE AGRICULTURAL LANDSCAPE

The fertile landscape of the Padan Plain offers major opportunities for both natural and agricultural practices. Its flat terrain facilitates intensive mechanized agriculture and relatively high crop yields, however, the same space would be very fitting for the creation of natural landscapes. The current wide agricultural landscapes are very suitable for transformation and facilitating GI. The areas have a very low density of buildings and structures, making it easy to transform. At the same time, the plot sizes are very large and relatively few different stakeholders need to be convinced of redevelopment practices. On the other hand, urban areas have a very high density, with many different stakeholders, which presents challenges in redevelopment efforts and the implementation of GI.




LAGO
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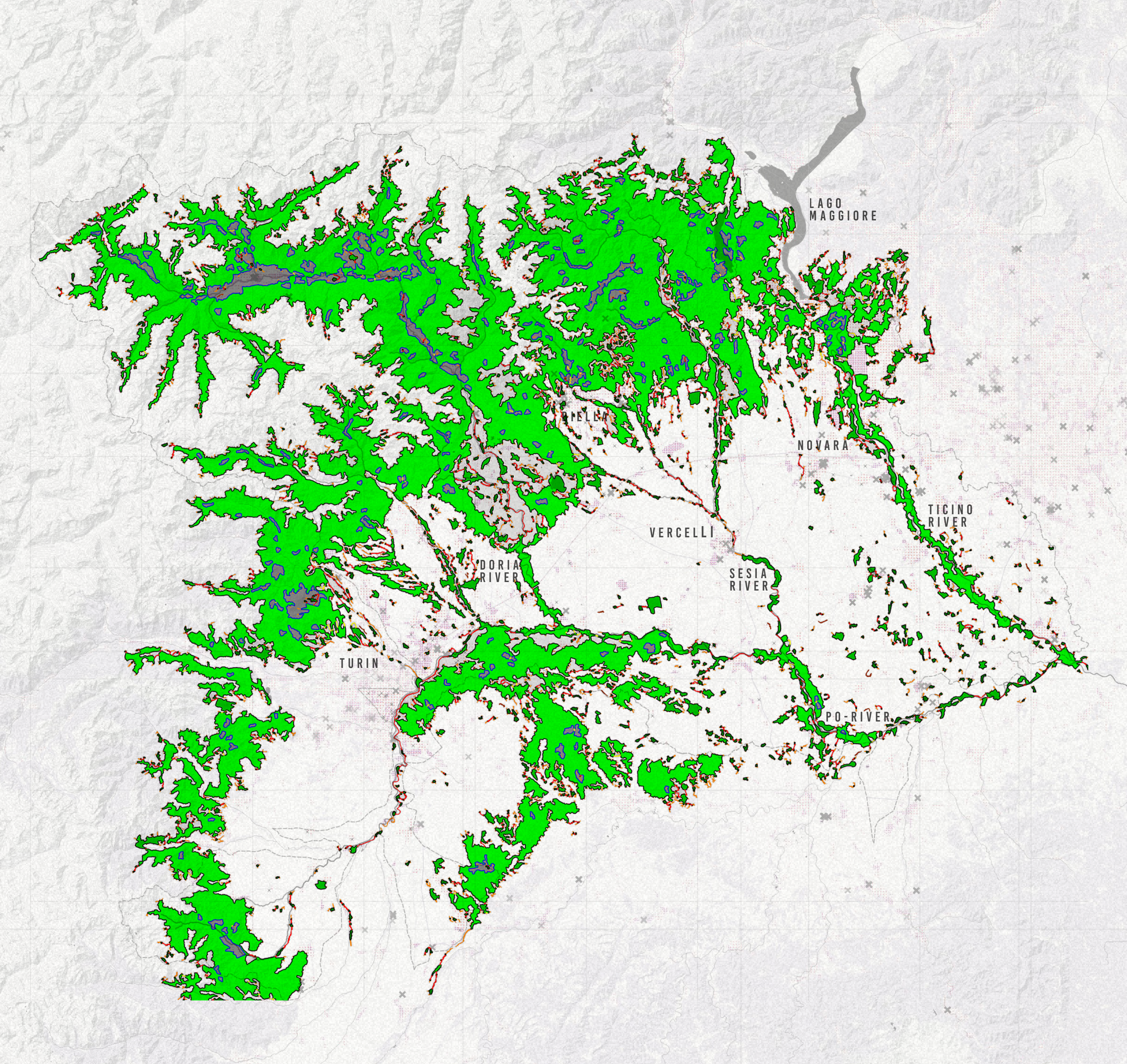
LAGO MAGGIORE
BIELLA
NOVARA
TICINO RIVER
VERCELLI
DORIA RIVER
SESIA RIVER
TURIN
PO-RIVER

SPATIAL COMPOSITION - MSPA

MORPHOLOGICAL COMPOSITION

To gain a better even deeper understanding of the regional natural landscape an MSPA is conducted. The Corine Land Cover dataset serves as the primary reference for the identification of natural land cover. The CLC classifies the landscape into 44 land cover types, categorized into 5 categories: 1. Artificial surfaces, 2. Agricultural areas, 3. Forests and semi-natural areas, 4. Wetlands, and 5. Water bodies. These categories however are not completely based on ecological value and don't allow the selection of just one of these five categories to be used to select natural habitats. For example, bare rocks, glaciers, and burnt areas are classified as semi-natural areas, even though they don't provide high ecological values or habitats. A better fitting selection of ecological areas is made including annual crops, agriculture with significant areas of natural vegetation, agroforestry areas, broad-leaved forests, coniferous forests, mixed forests, moors and heathland, sclerophyllous vegetation, transitional woodland-shrubs, inland marshes, peat bogs. Grasslands and agricultural areas are excluded from the selection as these do not have very high ecological value due to human disturbance, low vegetation density, and relatively low habitat qualities for wildlife.

Besides European data, regional spatial planning data with higher resolution was consulted. However, the difference in resulting regional landscape structures was insignificant on that large scale. Besides that, using this high-resolution data would be a tremendous strain on the computational strength of further analyses. Therefore, the decision was made to not include this data in the analysis and to continue with the data provided by the CLC dataset.

The selected natural structures are transformed into a binary raster map, with the natural landscape as the foreground (1) and other land cover types as the background (0). This serves as the input data for the MSPA in GuidosToolBox.

MSPA results show the morphological composition of the ecological landscape of the Piedmont region. 1699 ecological core areas are identified, making up a total of 16,60% of the complete landscape.

The biggest portion of the ecological core area consists of very large sources, with areas over 40ha. In total these huge sources make up 15,81% of the overall landscape. These ecological sources are mainly located along the feet of the Alps, forming the Northern and Western border of the territory, the Turin hills in the south, and the riparian green structures along the Po River and its main tributaries.

Only cores with an area larger than 8ha are considered ecologically relevant. There are 37 cores with a size between 8ha and 40ha in the research territory, making up 0,48% of the total landscape. The ecological cores are mainly located in the plains between the mountainous areas. Most of the cores are located near the larger ecological cores. The concentration of ecological cores decreases when the distance to the large ecological cores increases.

A total of 203 ecological cores with an area larger than 8ha are selected for the connectivity analysis in Conefor 2.6.

COMPONENT	RATIO (CORE/AREA)	COUNT
CORE(<8ha)	1.38/0.31	1466
CORE(8ha - 40ha)	2.11/0.48	135
CORE(>40ha)	69.52/15.81	68
ISLET	0.09/0.02	31
PERFORATION	2.79/0.63	198
EDGE	19.19/4.36	1046
LOOP	0.11/0.03	158
BRIDGE	0.99/0.23	1246
BRANCH	3.80/0.87	21633
Background	--/77.26	505/37158230

0 10 20 35 KM

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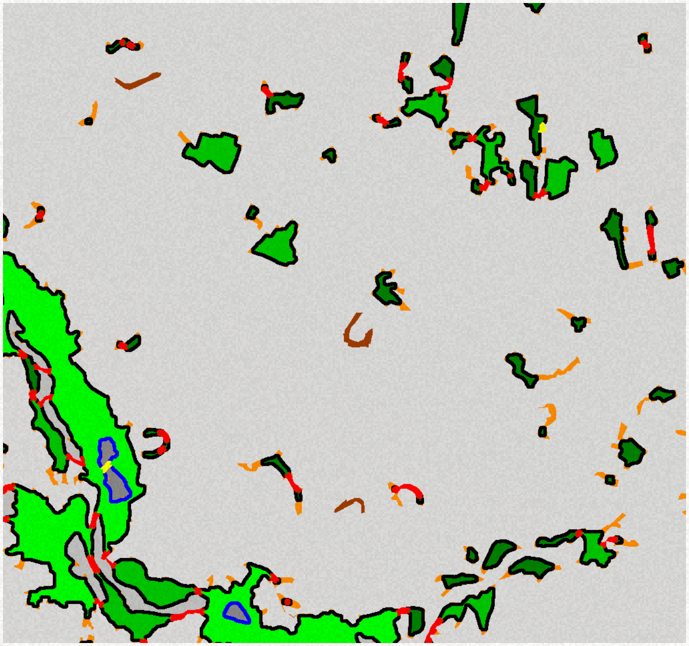
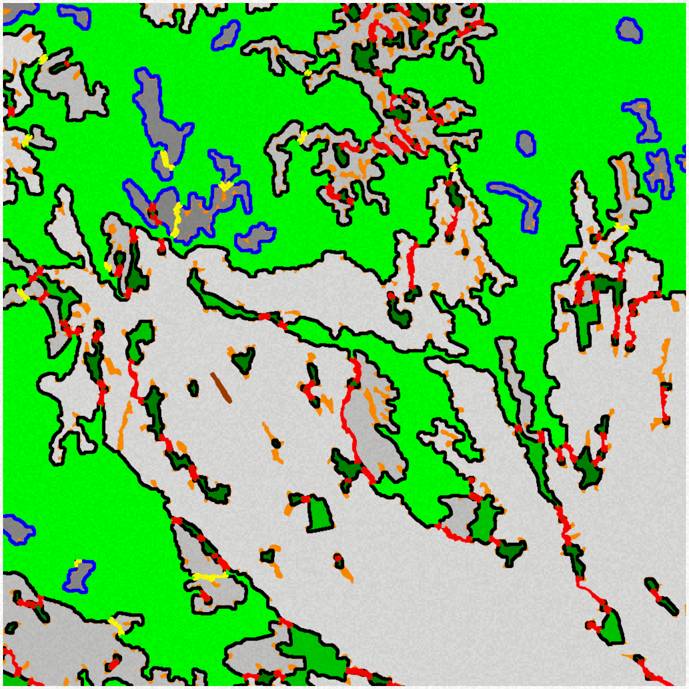


ECOLOGICAL ISLETS OF MORTARA

The results from the MSPA show a highly fragmented ecological landscape in the southeast of the territory, between the three rivers of the Sesia, Ticino, and the Po. The results show a lot of individual and unconnected core areas, as well as multiple islets and branches. Although these areas can be valuable for the local surroundings, they do not actively contribute to the regional ecological landscape. This area shows a lot of potential for improvement through local interventions and the introduction of green corridors to connect these individual cores, and more importantly, to the larger core areas around the rivers.

MSPA RESULTS OF THE AREA BETWEEN THE PO RIVER AND MORTARA



FRAGMENTED FOOTHILLS

Near the town of Biella, in the north of the research territory, another interesting phenomenon occurs. This area shows the transition from primarily natural landscapes on the slopes of the Alps and the increasingly artificial landscapes in the valley. The landscape fragmentation is clearly visible, and the once contiguous landscape now exists of smaller cores, connected through riparian green corridors. Conscious development is essential to prevent further landscape fragmentation in this area. Laying out a blueprint for the green structures in this area could prevent further deterioration of the natural landscape.

MSPA RESULTS OF THE AREA BETWEEN VERCELLI AND BIELLA

NETWORK CONNECTIVITY

USING A GRAPH THEORETIC APPROACH

The Graph-theoretic connectivity analysis in Conefor 2.6 shows the connectivity for the entire ecological network in the Piedmont region. All the patches from the green structure that have an area size of over 8 hectares are selected as ecologically relevant and are used for the analysis. For the connectivity analysis, the Probability of Connectivity (PC) is used as an index. This index uses the dispersal distances of selected fauna and compares that to the distance between the ecological sources in the analysis. The chance that an animal moves from one source point to another is based on the distance between the source point, and the dispersal characteristics of the selected animal species. In this analysis, the Western Honeybee (Apis mellifera L.) is used as a representative species for landscape connectivity. This species has a mean dispersal distance of 865m (Hagler et al., 2011), resulting in 865m with a probability of 0.5 as parameter input for the analysis. The analysis results in overall network connectivity values of 2.872547E11 for PC and 53,5961.5 for the Equivalent Connected Area (ECA(PC)). These values are a snapshot of the state of the entire network but do not inform design or conservation decisions. The figure on the right shows the connectivity values for the individual cores, showing the most essential elements of the green structure in dark green and less important elements in lighter shades. Higher importance in this case means that if this patch were to be removed, the connectivity of the entire network would suffer the most. If patches with low importance were to be removed, the connectivity of the landscape would be taken over by surrounding patches, securing the connectivity of the network. Patches with higher importance can't be supported by the surrounding green structure, meaning a greater loss in network connectivity.

By introducing new ecological core areas and new links the connectivity within the overall landscape would increase. An estimation of the impact of these new connections can be done using a similar approach. Links between the different ecological sources get a connectivity value based on the distance between the two source points. By improving the value of each individual link to 1, or 100%, at a time and recalculating the overall network connectivity values, the impact of improving the individual links becomes visible. The impact of improving links is shown in the figure. The thickness of the line represents the dPCconnector value, or simply put the impact on the overall network connectivity values.

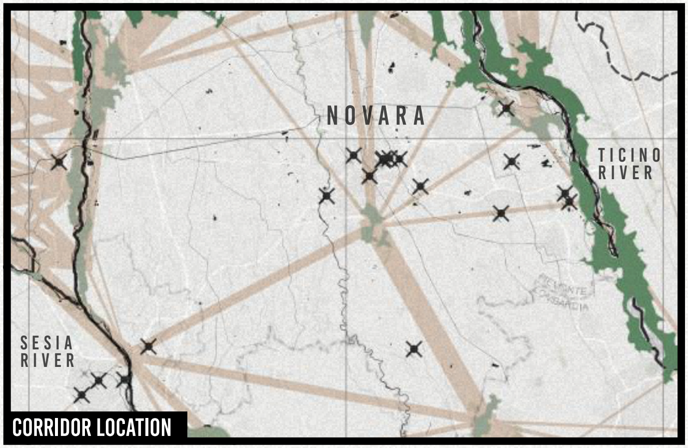
The results of the link improvement analysis show various areas with a higher concentration of improvement links with a relatively high impact on the network connectivity. Multiple hotspots can be found around the foothills of the Alps and in between the Po's tributary rivers. This is the result of landscape fragmentation and the presence of a lot of individual ecological sources in these areas, thus resulting in a lot of possible connections. In the plain, fewer sources are visible resulting in fewer possible links. However, the links in the plain regularly have higher potential impacts on the network.

A few locations were taken into consideration for hosting a new corridor. The area in the southeast of the research area, encompassing the area between Mortara and Pavia, exhibits a high concentration of potential links with relatively high dPCconnector values. However, the absence of contaminated sites makes this area uninteresting for this research as the transformation of contaminated sites and the implementation of phytoremediation is a core element of the design approach. On the other hand, the area between Turin and Chivasso is filled with contaminated locations and shows relatively many potential link improvements. Yet, the monotonous industrial landscape shows little interesting potential for showcasing different design strategies.

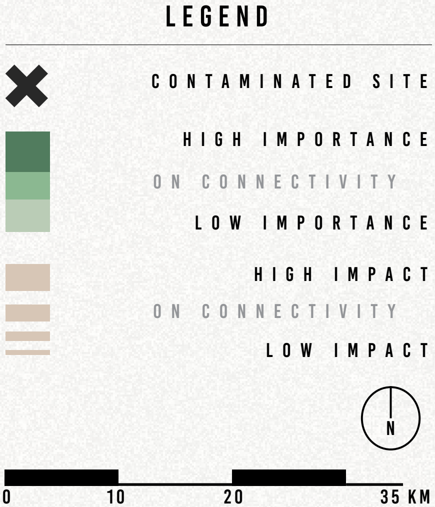
The area between Vercelli, Novara, and the Ticino Valley Natural Park shows an optimal balance between link improvement and the presence of remediation sites. Although very few links are possible, the links show a spatial overlap with contaminated sites, helping the integration of these contaminated sites into a new green corridor. Besides that, the corridor crosses a variety of landscapes, including large agricultural areas, urban core areas, and industrial zones. This offers a lot of possibilities for showcasing various design strategies and interventions on the local and corridor scale.

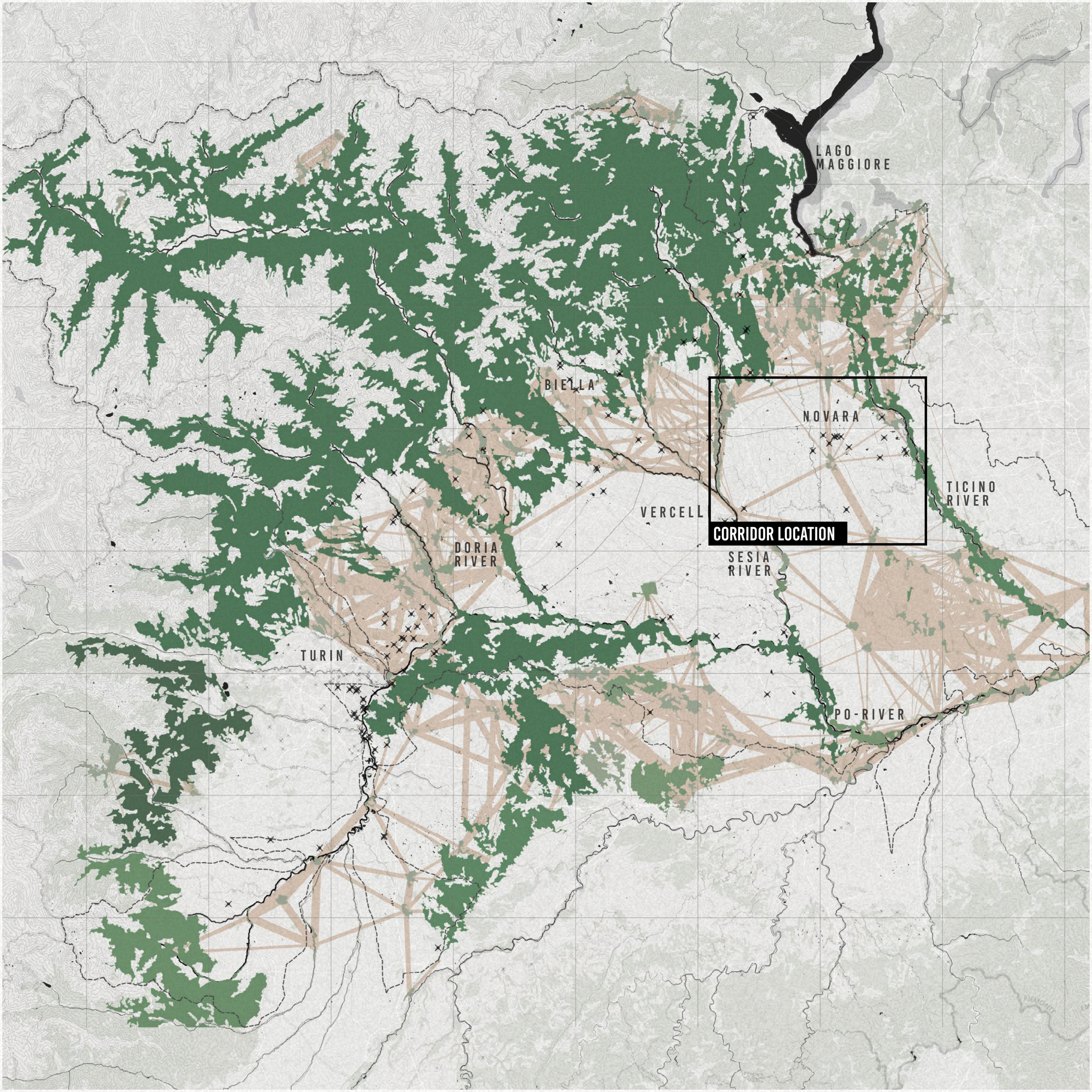
This selected corridor covers a total Euclidian length of approximately 35km and connects the riparian green of the Sesia River next to Vercelli to the Ticino River and the Ticino Valley Natural Park. The potential links between the Vercelli and Novara, and Novara and the Ticino, have dPCconnector values of 0.02 and 0.07 respectively, being moderately high. However, when both links are improved, this combined corridor works in synergy and results in a dPC value of approximately 0.34, ranking it within the top 4% of potential link improvement in terms of connectivity impact.

In conclusion, the potential corridor between the riparian areas of the Sesia and Ticino rivers, crossing the southern edge of the city of Novara shows potential from both quantitative and qualitative perspectives. This area is selected for further analysis and used in the next chapter for designing and assessing the green corridor.



ZOOM-IN OF THE SELECTED AREA BETWEEN THE SESIA AND TICINO RIVERS FOR PLANNING NEW GI.




LAGO MAGGIORE
BIELLA
NOVARA
TICINO RIVER
VERCELLI
CORRIDOR LOCATION
SESIA RIVER
DORIA RIVER
TURIN
PO-RIVER

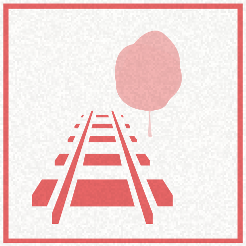
04

CORRIDOR DESIGN

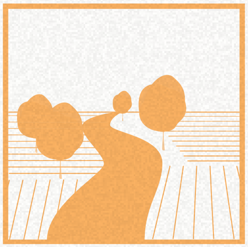
STRATEGIES & CONTEXT

INTRODUCTION

As aforementioned, green corridors are not the simple straight lines that are used in the connectivity analysis. In reality, these lines are closely connected to the local context and surroundings. The corridor crosses multiple landscapes and can be designed in various ways. To guide the design of the corridor four different strategies are used: I. Alongside linear grey infrastructure, II. Landscape centered, III. Creating rural-urban gradients, and IV. Synchronizing with the urban green structure. Each of these strategies has its advantages and opportunities and can be implemented in different ways. The strategies, their implications, and the goals they pursue are described extensively in the following pages.

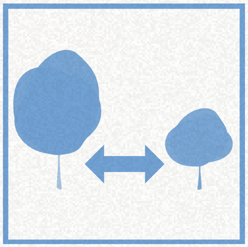


GREY/GREEN INFRA-STRUCTURE



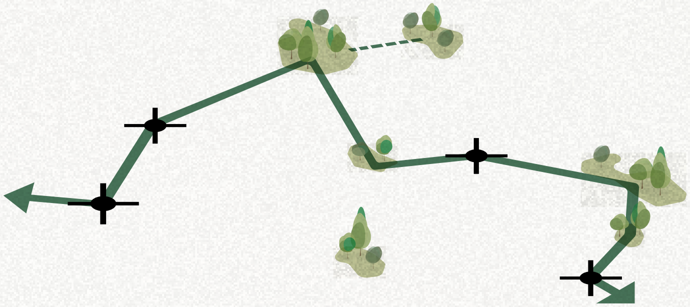
LANDSCAPE CENTERED

GRADIENT CREATION

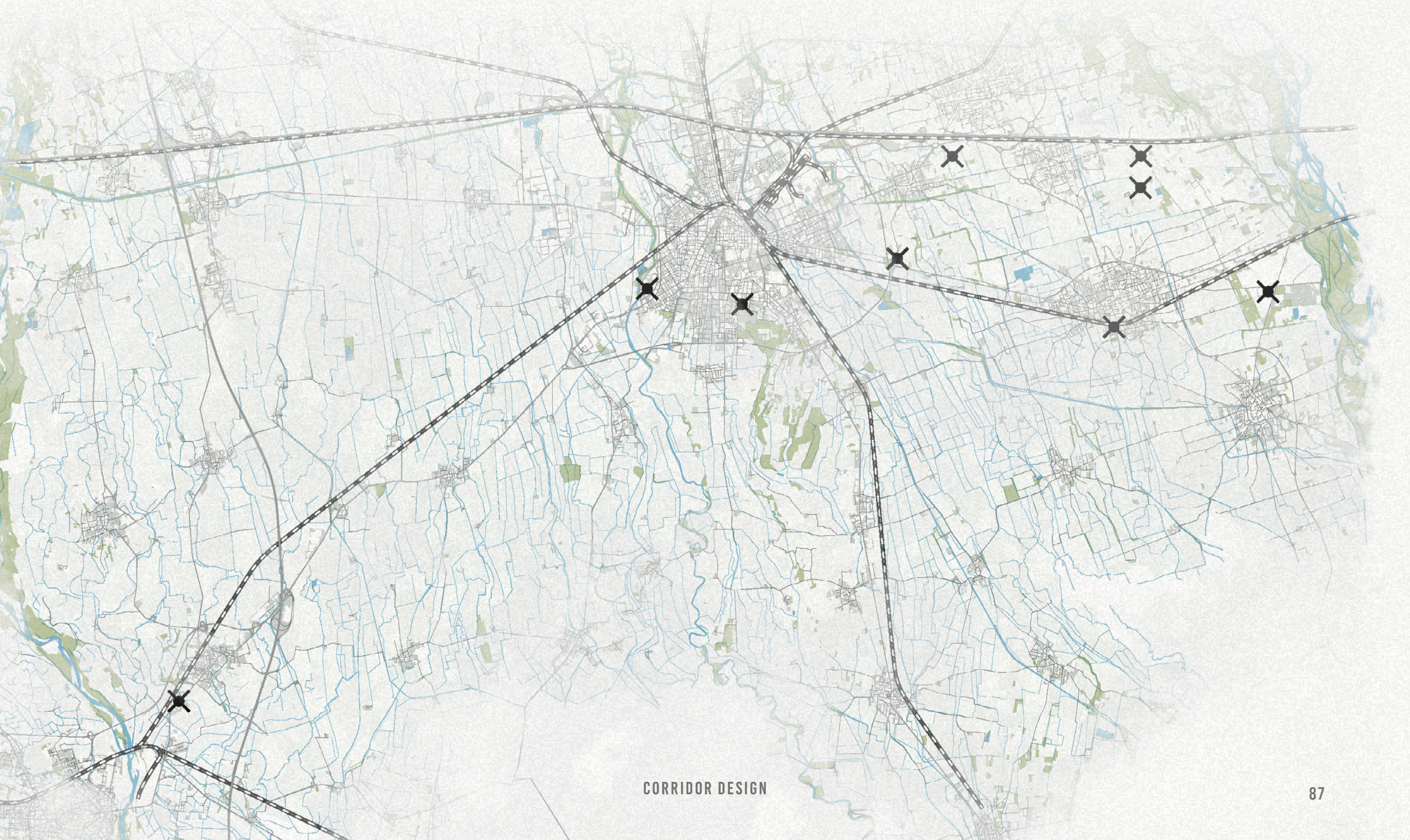


SYNCING WITH THE URBAN GREEN

CONNECT THE DOTS



The graph-theoretic approach to ecological network connectivity is very valuable for quantifying impacts and the potential that new connections might have. However, it would be very improvident to see the ecological network as simple dots and lines. In reality, these links are not linear, but they follow the territory and its local characteristics. The potential links still have to be translated into connections that follow this local landscape. The goal is to include as many contaminated sites as possible while integrating the local green patches that are on the path between those sites, including the smaller ecological patches not included in the regional assessment from the previous chapter. This diagram shows a simplified concept of 'connecting the dots' whilst integrating local green patches.



I. GREY/GREEN INFRASTRUCTURE

BUFFERING

Linear grey infrastructures offer great opportunities for the introduction of green elements. As linear grey infrastructure often covers greater distances this is ideal for attaching linear green elements and connecting green patches over greater distances as well. Besides that these infrastructures often have barren areas alongside them, as policies building next to these infrastructures is often not allowed. Air quality in areas along highways is bad, traffic, be it in the forms of road or train traffic, causes serious noise hinder, and these infrastructures can be dangerous for children. Health dangers because of intensively used roads and railroad tracks can be very serious. The same accounts for wildlife and animals for who the roadside greenery is their habitat. Introducing green structures along infrastructure increases the number of wildlife-vehicle collisions, especially when the green structure is situated on both sides of the linear infrastructure (Fedorca et al., 2021). This is a risk for the animals as well as for the car drivers. Besides that, the noise produced by the infrastructure is not beneficial for the living environments of the animal species present. Studies show that most bird species need a distance of 290-540 meters to noisy roads or railroads in order to live. However, these values vary a lot between species and landscapes. In areas with merely grasslands distances of over 400 meters are usually kept as a threshold value. Bird species that often live in or near urban centers are also less prone to road noise. However, when designed well these linear GI can be used as multimechanism buffers. In this way, they capture the airborne pollution, act as a noise block towards the surrounding landscape, and form a physical and visual barrier between the landscape and the grey infrastructure. The design goal of this strategy is to buffer the pollution and disturbance of the grey infrastructure towards the surrounding landscape. In some way, this is sacrificing the quality of the green infrastructure itself to improve the surrounding landscape.

BUFFERING TRAFFIC POLLUTION

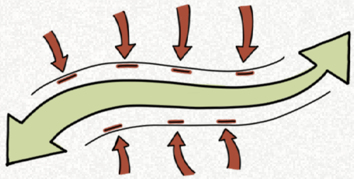
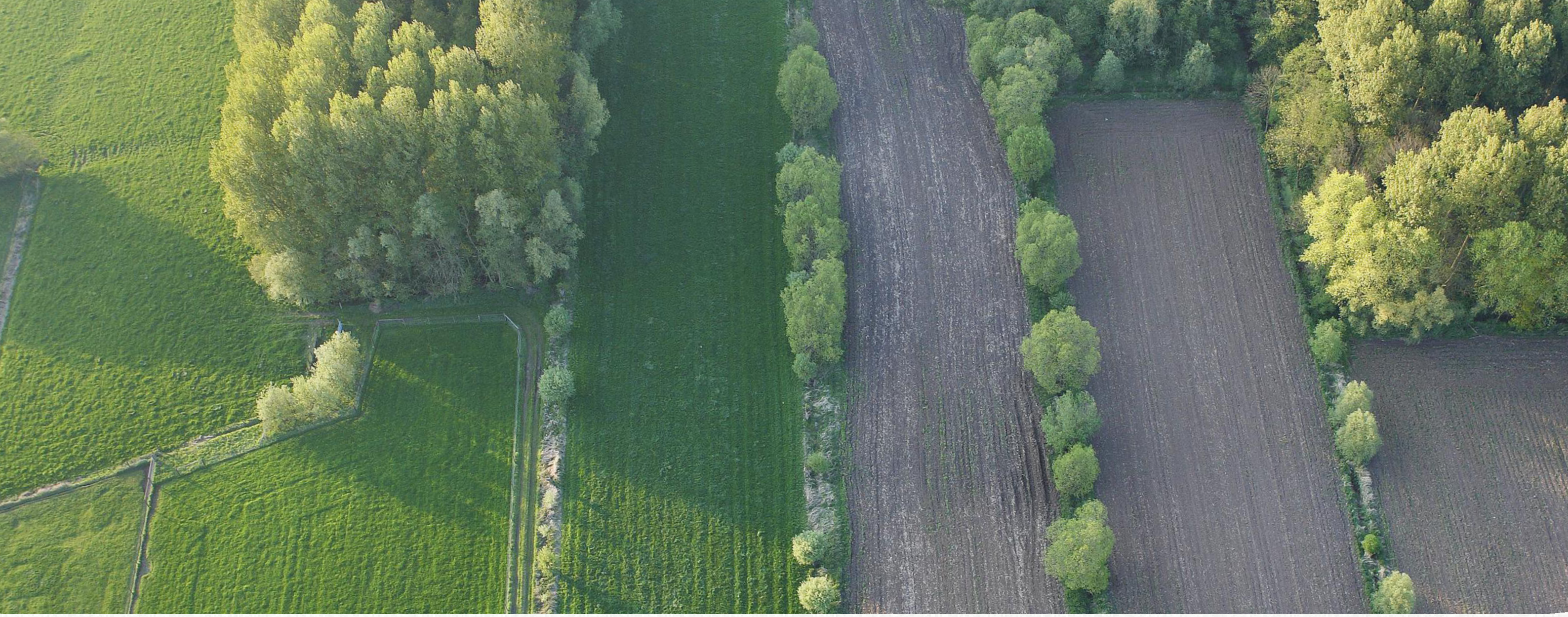


IMAGE: OWN IMAGE



II. LANDSCAPE CENTERED

OPTIMIZING ES

The landscape-centered approach can be seen as the inverse of the prior strategy. Instead of sticking alongside the grey infrastructure and acting like a border between the natural landscape and the infrastructure, this strategy keeps as far away from artificial interruptions as possible. This approach is focused on the quality of the corridor itself and the ES it can provide for the surrounding landscape. In rural landscapes, this is mainly focused on regulating and supporting ES. Increased biodiversity, better pollination, nutrient cycling, and erosion protection are just a few of the possible benefits of introducing the green corridor into the agricultural landscape.

However, there is also some criticism on the introduction of GI in these areas. The introduction of more biodiversity and new species potentially means more pests, insects, fungi, and weeds. As most of the agricultural areas are completely controlled and managed, this could be a threat to the status quo. Simultaneously, the introduced greenery acts as another water and nutrient consumer competing with the agricultural crops (McIntyre et al., 1997). However, when done thoughtfully this could also mean the introduction of natural pest management, promoting more ecological farming and sustainable food production practices.

As the corridor is a linear structure, there is a need for linear landscape elements that could guide the corridor. As the landscape of the study region consists of mainly irrigated agriculture there are a lot of irrigation channels. Following the main channels and creating riparian structures is one way to go. Other options include the following of parcel borders. As landscape variety is essential for habitat quality some complete parcels have to be afforested.

OPTIMIZING ES IN SURROUNDING LANDSCAPES

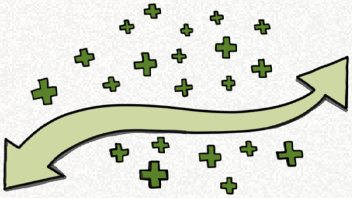


IMAGE: OWN IMAGE

III. GRADIENT CREATION

The inhabitants of the region surrounding Novara and Vercelli are very proud of their world-famous rice production. The risotto rice from the area is exported to countries worldwide. Food, and in this area especially rice, is an important part of the local culture. However, when looking at the spatial relationships between the agricultural rice landscapes and the urban, no interaction is visible. The agricultural landscape exists out of privatized areas, often accessible but uninviting for the community. Road pavement ends at the urban edges and continues unpaved into the agricultural landscape, sidewalks disappear completely and there is no sign of recreational activities within the beautiful rural landscapes. By introducing green areas along the urban edges and creating gradients in the agricultural landscapes, this ignored relationship can find a way again. In the form of orchards, agritourism, petting zoos, community gardens, peri-urban parks, and other interventions, people get attracted to the urban fringes and softly get in touch with agriculture again. Reestablishing this relationship further strengthens the pride in local food production and creates valuable green gathering spaces at the urban edges.

RECONNECTING TO AGRICULTURE

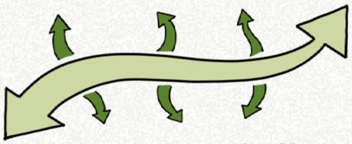


IMAGE: OWN IMAGE

IV. SYNCING WITH THE URBAN GREEN

As some of the contaminated sites are located within urban areas, the regional green corridor has to be incorporated into the urban tissue as well. Using the existing, local urban green structures and connecting to this from the regional scale, synergies get created, resulting in valuable well-connected spaces within and outside of the urban cores. Research in Madrid shows the benefits of carefully connecting peri-urban greenery and Open Space Strategies (OSS) within the cities. Connecting the urban green patches with the bigger scale improves the ES within the city as well, resulting in cleaner air, improved pollination, increased health and mental well-being, and more space for wildlife for example.

The goal of this strategy is to improve the local urban green structures by connecting them with the peri-urban and rural green. Locations within the urban part of the green corridor should serve as meaningful and ecological gathering places, be it in the form of parks, community gardens, sports facilities, or others.

CREATING SOCIAL OPPORTUNITIES

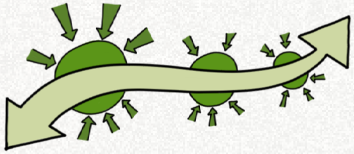


IMAGE: CLAIRE DROPPERT (2018, HET PARK ROTTERDAM, IMAGE GATHERED VIA HTTPS://WWW.ROTTERDAMCENTRUM.NL/ONTDEK/STREET-ART-PARKEN

CONTEXT-STRATEGY COMPATIBILITY

The aforementioned strategies are bound to certain landscape characteristics. Logically, it would be impossible to connect green infrastructure with urban green structures within a completely rural landscape, and using a landscape-centered approach focused on improving agriculture-related ES is not possible in dense urban landscapes. The following short passages illustrate the implementation of the different strategies within different contexts. To be able to connect the strategies to the territory, the landscape has been classified into three different categories: rural, peri-urban, and urban. Each has its own urban density and spatial composition.

I. RURAL LANDSCAPE

The rural landscape is characterized by natural features, low population density, agricultural land use, and wide vistas. The rural landscape is often extensive with large monotonous land use. In current times the rural landscape is often crossed by large infrastructures in the form of highways, railroad tracks, electricity poles, etc. GI within rural landscapes with intensive agricultural practices are often found in the form of riparian structures or along infrastructures. On the right are two exemplary cases of the riparian green structures in Leusden, the Netherlands (left), and linear green structures along the highway in Barneveld, the Netherlands (right). Continuing into the corridor design, strategies I. Alongside Grey Infrastructure and II. Landscape-centered will be used and assessed in rural contexts

TOP: AIRBUS MAXAR (2024), *RIPARIAN GREEN AROUND LEUSDEN*, GATHERED FROM HTTPS://WWW.MAPS.GOOGLE.COM
BOTTOM: AIRBUS MAXAR (2024), *A1-HIGHWAY AROUND BARNEVELD*, GATHERED FROM HTTPS://WWW.MAPS.GOOGLE.COM

II. PERI-URBAN LANDSCAPES

Peri-urban landscapes are transitional zones located between urban and rural areas, characterized by a mix of urban and rural features and activities. These areas experience the dispersal of urban growth towards rural surroundings, leading to a unique landscape that combines elements of both urban and rural environments. Peri-urban landscapes are often marked by a blend of social and economic activities from urban and rural areas, creating a dynamic and evolving landscape (Salem, 2015).

As the peri-urban landscape has urban characteristics as well as rural landscape elements, all four strategies can and should be implemented within this type of landscape. Peri-urban landscapes often offer opportunities for diverse land-use types as recreational areas, cultural heritage sites, sports parks, and other green spaces. Peri-urban sites play a major role in connecting regional green systems with urban green structures. L'Horta de Valencia is a great showcase of the value of peri-urban space (Miralles i Garcia, 2015).

TOP: AIRBUS MAXAR TECHNOLOGIES (2024), RIPARIAN GREEN AROUND LEUSDEN, GATHERED FROM HTTPS://WWW.MAPS.GOOGLE.COM
SECOND FROM TOP: AIRBUS MAXAR TECHNOLOGIES (2024), *AGRICAMPING IN VLISSINGEN*, GATHERED FROM HTTPS://WWW.MAPS.GOOGLE.COM
THIRD FROM TOP: AIRBUS MAXAR TECHNOLOGIES (2024), *PERI-URBAN GREEN IN THE ZUIDPOLDER, BARENDRECHT*, GATHERED FROM HTTPS://WWW.MAPS.GOOGLE.COM
BOTTOM: AIRBUS MAXAR TECHNOLOGIES (2024), *A1-HIGHWAY AROUND BARNEVELD*, GATHERED FROM HTTPS://WWW.MAPS.GOOGLE.COM

III. URBAN LANDSCAPES

Moving towards even denser landscapes, we arrive at the urban landscape. The urban landscape encompasses a diverse range of land use but is characterized by physical man-made structures and high population density. Urban areas include residential, commercial, industrial, and recreational areas and are usually very dynamic and subject to changes and development. As the urban tissue is often very dense and intensely used, ecological values are relatively low due to the often small footprint of these green areas and the disturbance of humans and urban activities. However, it is important to support urban green to create livable urban environments and mitigate climate change. For designing ecological corridors in urban environments, two main strategies could be followed: going through the urban tissue and integrating the local urban green structure (IV. Syncing with the urban) or following the city edges and going along the urban borders (III. Creating Rural-Urban Gradients). The images show the creation of an urban-rural gradient utilizing an agricamping Vlissingen, the Netherlands, and the connection between urban green structures and larger peri-urban ecological landscapes in Barendrecht, the Netherlands.

TOP: AIRBUS MAXAR TECHNOLOGIES (2024), *AGRICAMPING IN VLISSINGEN*, GATHERED FROM HTTPS://WWW.MAPS.GOOGLE.COM
BOTTOM: AIRBUS MAXAR TECHNOLOGIES (2024), *PERI-URBAN GREEN IN THE ZUIDPOLDER, BARENDRECHT*, GATHERED FROM HTTPS://WWW.MAPS.GOOGLE.COM

ECOLOGICAL RESISTANCE

USING ERS-MODELS FOR ECOLOGICAL ASSESSMENT

Mapping the spatial distribution of ecological resistance factors gives insight into the most likely corridors for species movement and helps to focus conservation efforts on the most important locations. Current studies into ecological conservation optimization often use the concepts of ecological resistance combined with a Minimum Cumulative Resistance (MCR) of Least Cost Path (LCP) approach to determine the current and potential ecological corridors. These approaches calculate the route from the source to the endpoint which poses the least resistance (or costs). These calculated routes are considered to be the most plausible routes for species movement and thus important for conservation. A similar principle is applied in this location selection for new GI design, where the ERS model is used as an assessment tool for evaluating different design options. However, the MCR or LCP methods are omitted to allow for more creative and flexible design options, where the focus lies on more than just ecological resistance.

The ecological resistance map is a combination of various individual ecological resistance factors. The used factors vary between studies, as the studies differ in researched animal species, spatial context, or research field. As this study focuses on general landscape connectivity no species-specific data layers are used. Based on the literature three major categories of ecological resistance can be defined: natural conditions, landscape types, and human disturbance. Four different data layers were used: the built-up index, landscape type, vegetation density index, and road density. These layers give insight into the ecological disturbance from human, landscape, and natural factors and therefore should give a sufficient overview of the ecological resistance. The ecological resistance map has a value range from 1 to 5, with 1 being the least resistant to movement species, and thus the most natural, and 5 poses the biggest resistance.

In the ecological resistance surface map on page 98, the urban areas are clearly visible. The same accounts for major roads and highways, industrial zones, and to a certain extent railroad connections. The agricultural landscape presents little resistance, the only variation in resistance values derives from the vegetation density in the agricultural field and the disturbance of infrastructure or built-up areas around farms and houses. All the used values are relative and normalized for the study area and cannot simply be duplicated into other study areas, but have to be redefined according to the local situation.

Keep in mind that this ecological resistance map is merely an indication of the real situation. A lot of possible resistance factors are not taken into account. To be a more adequate model the resistance map could be supplemented with information on for example noise, air quality levels, distances to roads or settlements, distances to rivers, vegetation types, etc. However, due to time and data constraints, this is not included and the used data is deemed sufficient to give a little insight into the ecological landscape.

All in all, this ecological resistance map is accurate enough to indicate areas with high resistance and help guide the design process of the new ecological corridor. Ecological resistance is used as an assessment for the different design strategies and uncovers the bottlenecks in the selected strategy. By quantifying the ecological resistance, well-argued design decisions can be made based on average and cumulative ecological resistance, and the covered distance.

ECOLOGICAL RESISTANCE

BUILT-UP INDEX

Building density and built-up areas form a threat to species movement. The impervious surfaces do not allow for hospitable environments for most species and the lack of vegetation forms a huge barrier for species movement. For this data layer, the Normalized Difference Built-up Index (NBDI) is used, supplied by the Copernicus Land Monitoring Service. The values in this layer show the ratio of built areas to unbuilt areas, ranging from -1 for completely built-up areas to 1 for completely permeable areas. The ecological resistance is based on a range from 1 to 5, using only integers. All values ranging from -1 to -0.6 are classified as 5, -0.6 to -0.2 is classified as 4, -0.2 to 0.2 gets a value of 3, 0.2 to 0.6 resembles a 4, and 0.6 to 1 results in a value of 1 for ecological resistance.

LANDSCAPE TYPE

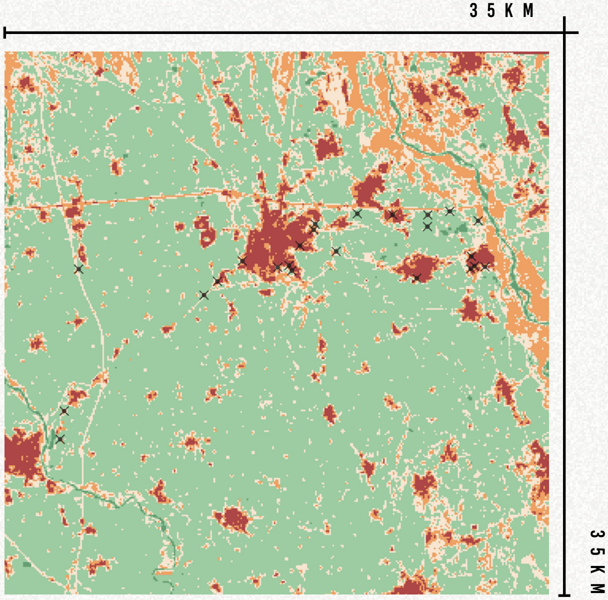
The landscape type is based on the Corine Land Cover data from Copernicus Land Monitoring Services. The CLC is classified into 5 categories, resembling ecological resistance. Based on literature (Liu et al., 2023) these categories are forests and woodlands (1), wetlands (2), agricultural and cultivated land (3), water (4), and constructed lands (5).

VEGETATION DENSITY

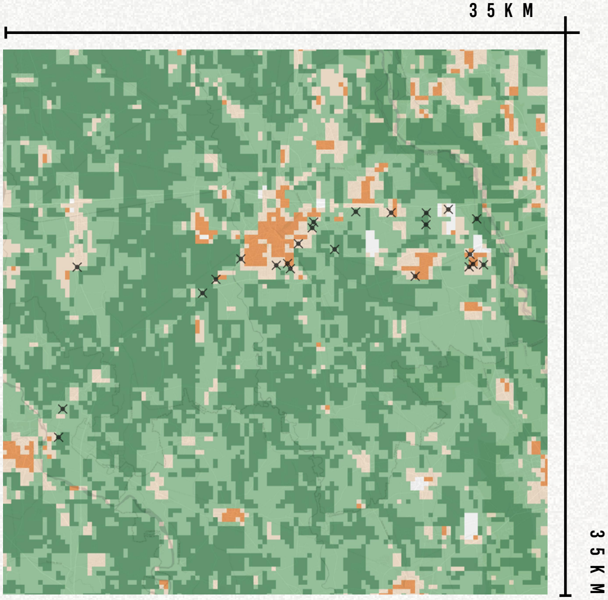
Vegetation density, contrary to the Built-Up Index, is very beneficial for species movement. Dense vegetation provides habitat, food, and shelter. Vegetation density is based on the Remote Sensing data from the Copernicus Land Monitoring Service, called the Normalized Difference Vegetation Index (NDVI). This layer again ranges from -1 to 1 and is classified in the same way as the NDBI, with -1 being the highest resistance (5) and 1 being the lowest (1).

ROAD DENSITY

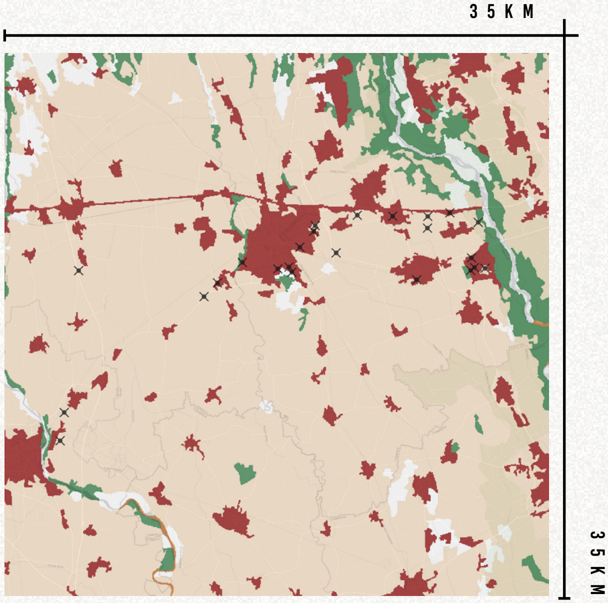
Roads and linear infrastructure are a major cause of landscape fragmentation and impede species movement. Not only by spatial distribution and reduced permeability but also through noise pollution. Road density is taken as an index for traffic and human disturbance and is calculated using the road entities gathered from OpenStreetMap. Road density is expressed in km/km2 with a resolution of 50mx50m. Again, the values are classified into equal parts ranging from 1 to 5, with 1 having the lowest road density and 5 the highest road density.



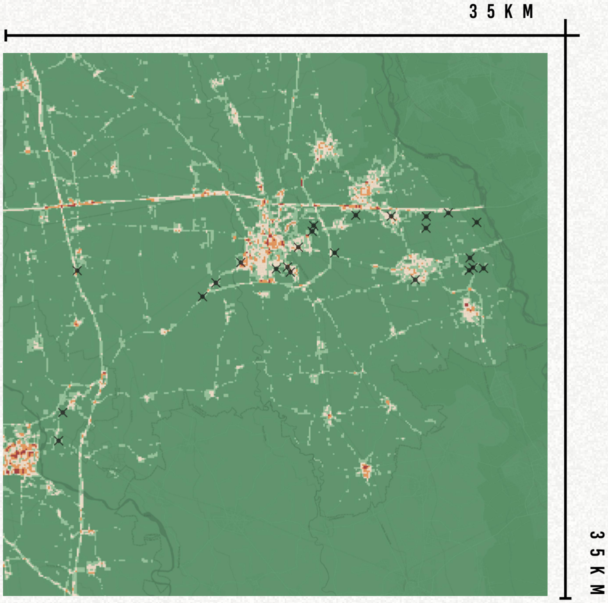
NORMALIZED DIFFERENCE BUILT-UP INDEX



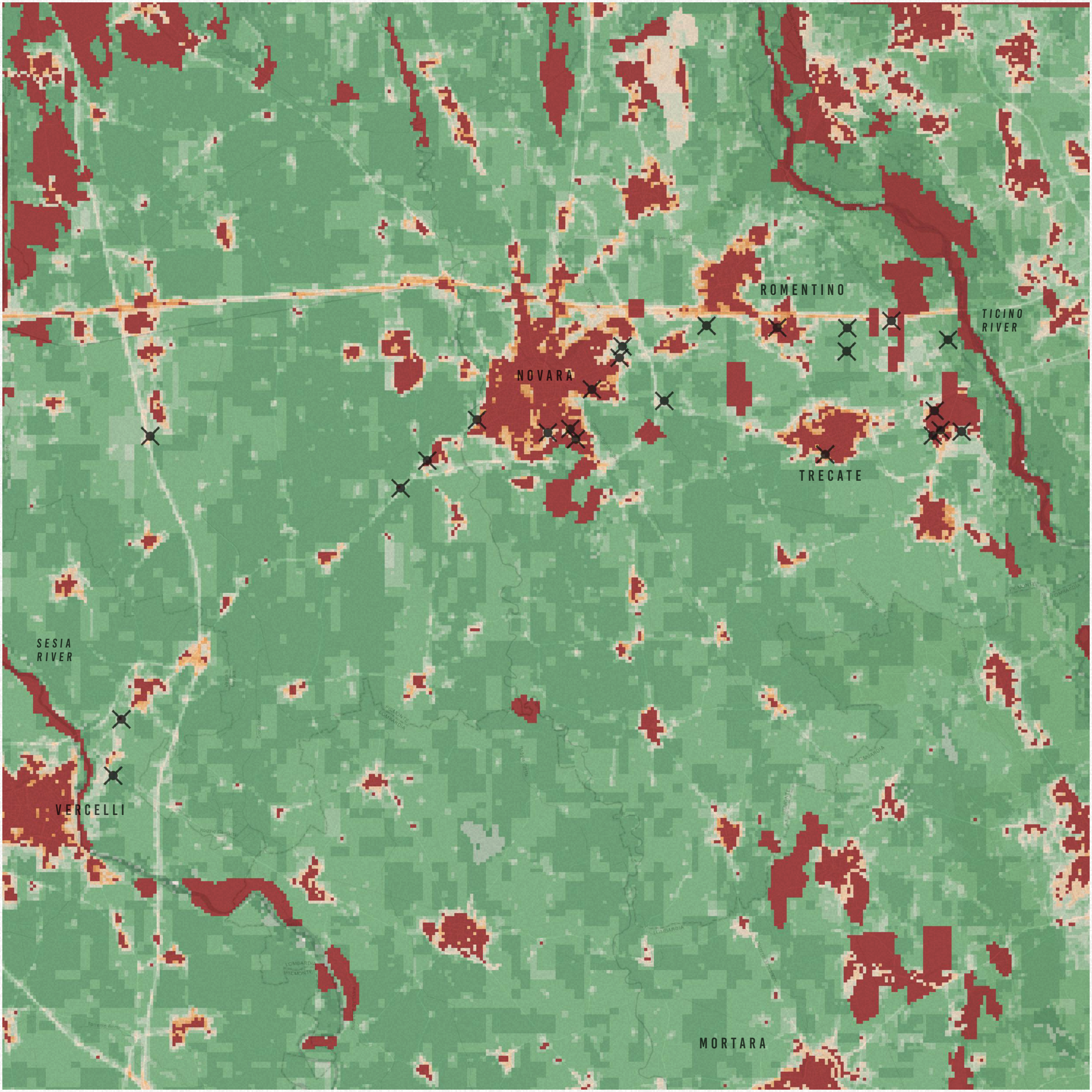
NORMALIZED DIFFERENCE VEGETATION INDEX



LAND USE/LAND COVER



ROAD DENSITY

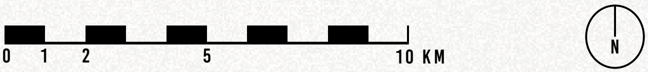

ROMENTINO
TICINO RIVER
NOVARA
TRECATE
SESIA RIVER
VERCELLI
MORTARA

CONCLUSION

An ERS model is established for the corridor design location, based on various natural and human factors. The compiled map can be used as a starting point and reference when creating the corridor path design options, as well as an assessment tool for calculating the ecological resistance of these options. The following pages are dedicated to the implementation of the design strategies to create the different design options, after which the ERS model is used for assessment and optimization purposes.

LEGEND

- HIGH ECOLOGICAL RESISTANCE (5)
- MID-HIGH ECOLOGICAL RESISTANCE (4)
- MID ECOLOGICAL RESISTANCE (3)
- MID-LOW ECOLOGICAL RESISTANCE (2)
- LOW ECOLOGICAL RESISTANCE (1)



IMPLEMENTATION & ASSESSMENT

INTRODUCTION

The four developed design strategies are implemented in the corridor area, selected in the previous chapter. The goal is to connect the different remediation sites while incorporating as much of the local green patches as possible and to fit in with the local landscape. To be able to efficiently run the assessments, the entire corridor is divided into three segments, based on the primary landscape that it goes through. For each segment, the fitting design strategies are applied to the situation. After this, the ERS model is used to quantify the faced resistance and assess the different design options

The assessed design options are used as the foundation of a designed corridor path that combines the best parts of each design option. Afterward, the ERS model is used for further optimization efforts of the designed corridor path, focusing on minimizing ecological resistance and the provisioning of ES. This section ends with a plan for a green corridor, that connects the riparian structures of the Sesia and Ticino rivers and incorporates the contaminated sites and local green patches on its way.

ASSESSMENT METHOD

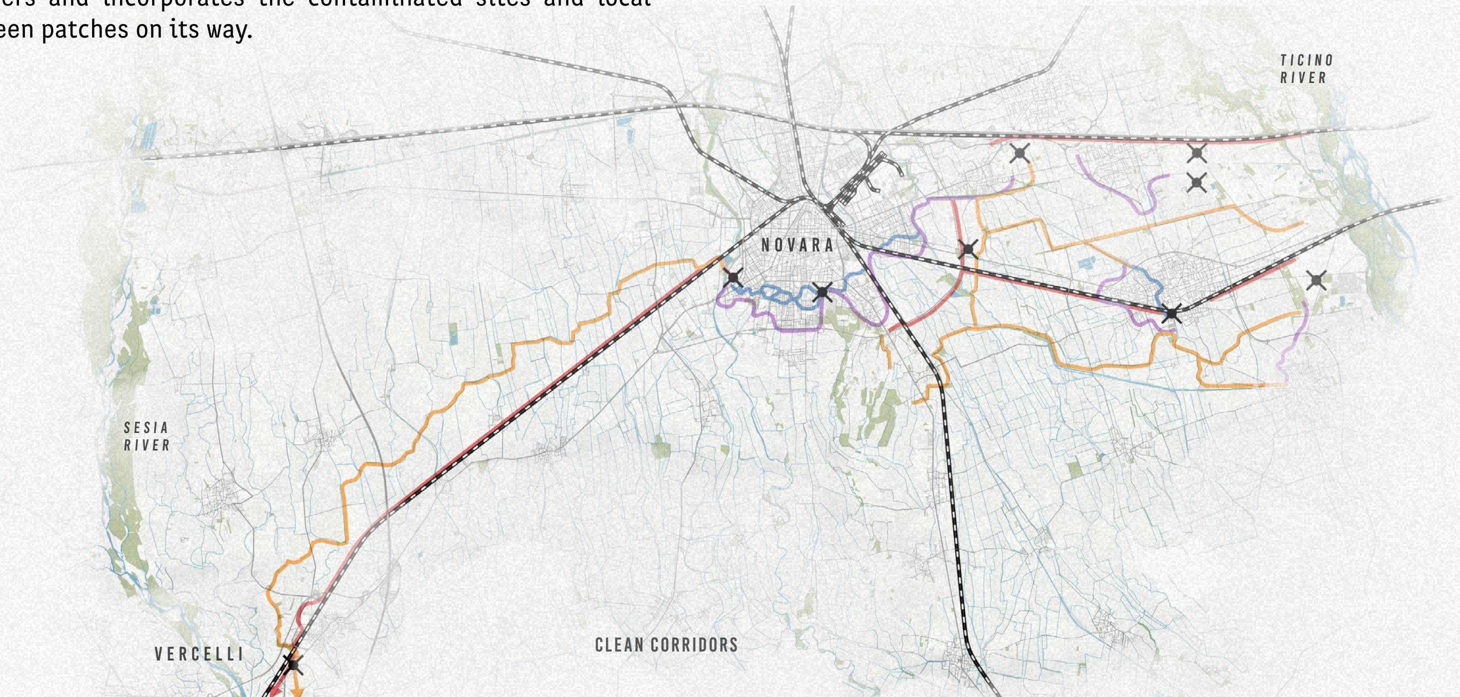
1. Selecting the appropriate design strategies based on landscape type and context

2. Developing design options following the selected design strategies

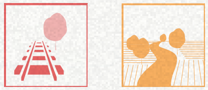
3. Quantifying ecological resistance faced by the selected design options

4. Creating an integrated design from the multiple design options focused on minimizing ecological resistance

5. Assessing and optimizing the designed corridor path



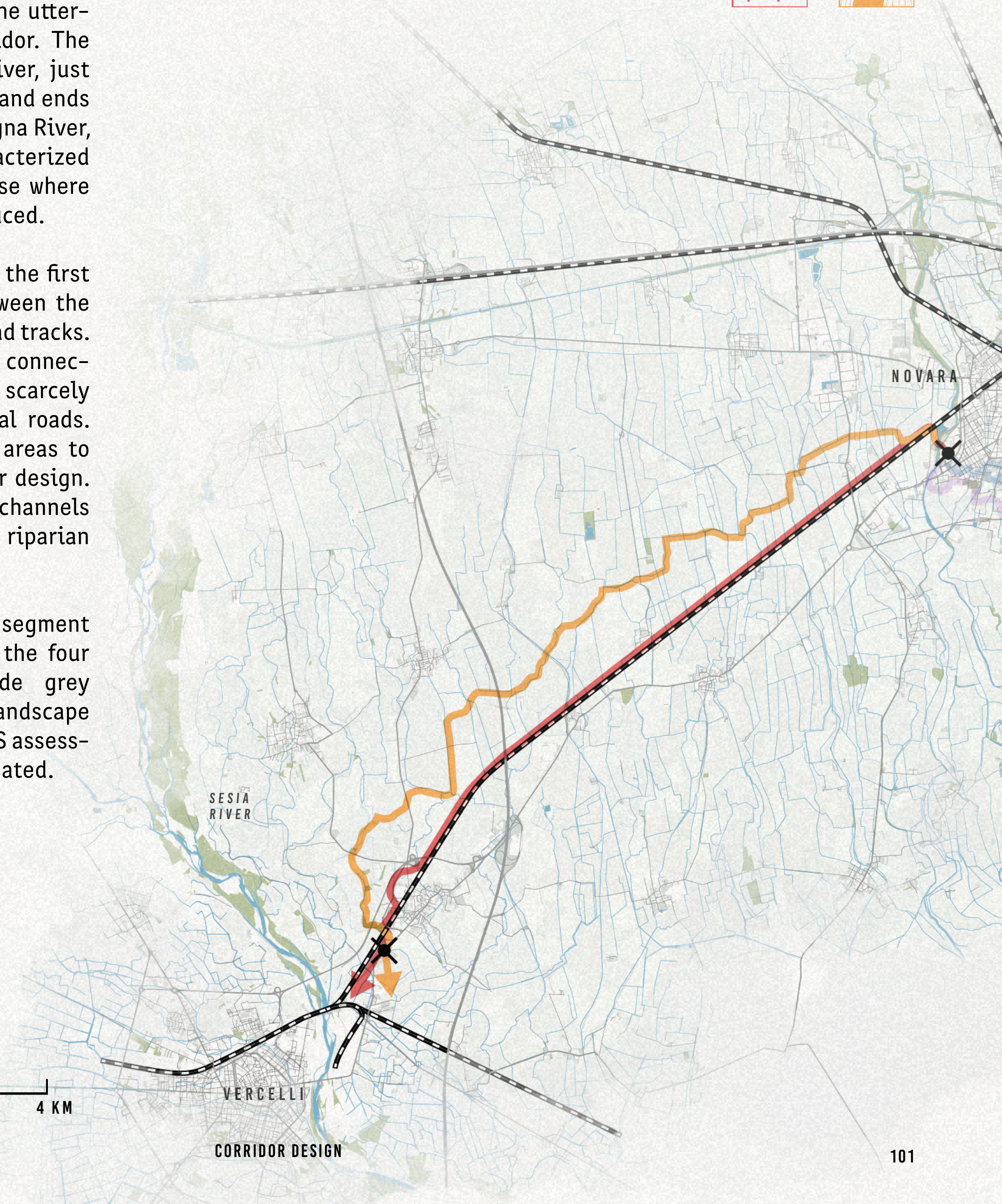
SEGMENT I - RURAL VERCELLI

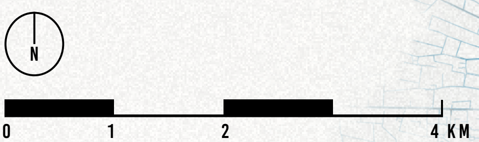


The first section is situated in the uttermost western part of the corridor. The segment starts at the Sesia River, just northwest of the city of Vercelli, and ends at the green riverbeds of the Arogna River, west of Novara. The area is characterized by intensive agricultural land use where mainly rice and cereals are produced.

The start of the segment houses the first remediation site, nestled in between the Strada Provinciale and the railroad tracks. The railroad tracks form a linear connection towards Novara and are scarcely crossed with provincial and local roads. The area shows limited natural areas to be incorporated into the corridor design. The abundance of irrigation channels creates options for designing riparian green structures.

Based on the rural context, this segment is primarily suitable for two of the four design strategies: 1. Alongside grey infrastructure (Yellow) and 2. Landscape centered (Red). Following the ERS assessment, a third design option is created.





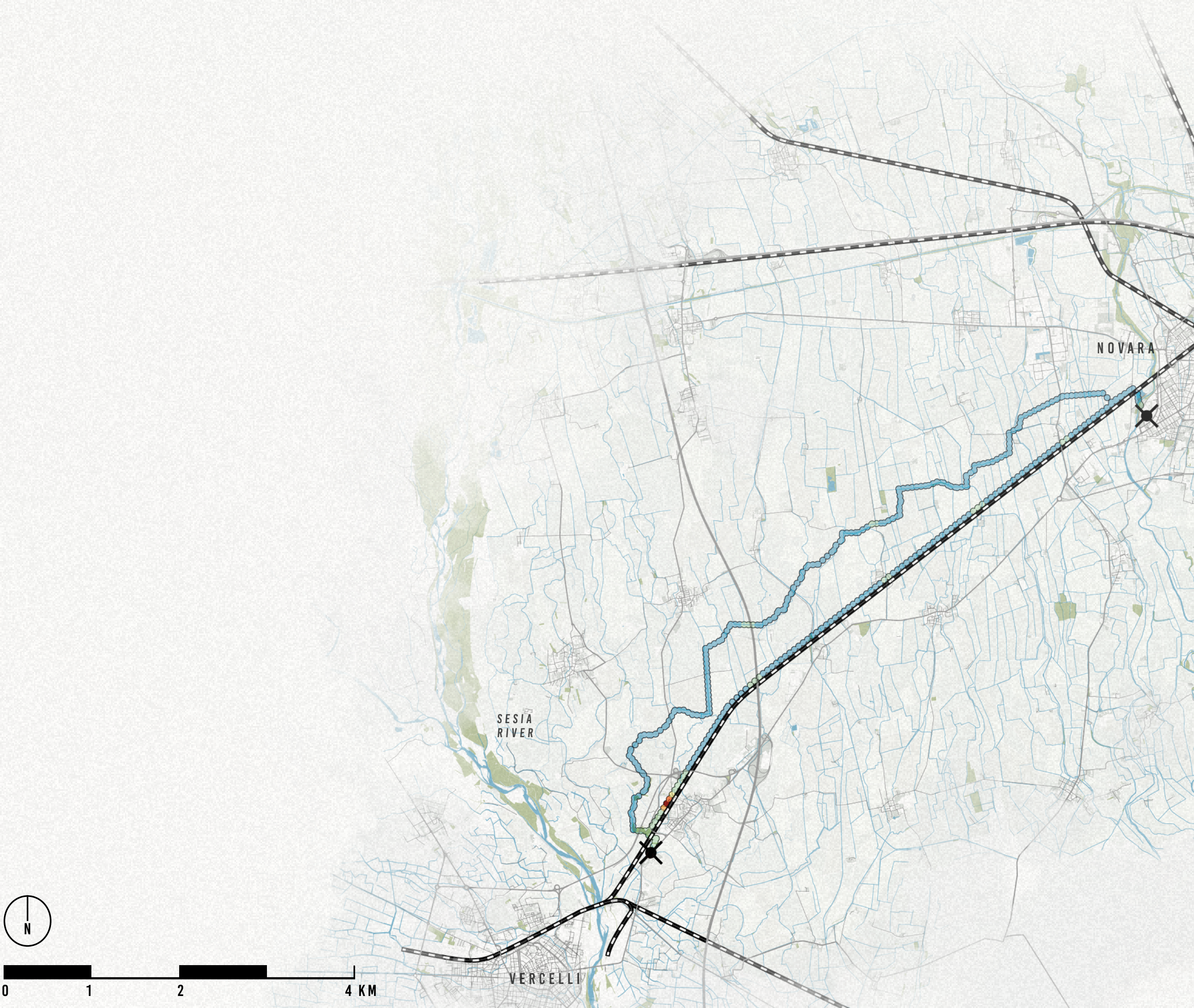
ASSESSMENT RESULTS

Strategy 1 – ES optimization		Strategy 2 – Following grey infrastructure	
Cumulative resistance	519.7	430.9	Cumulative resistance
Mean resistance	1.83	1.94	Mean resistance
Median resistance	1.75	1.78	Median resistance
Overall distance	28,355 meter	22,209 meter	Overall distance

RESISTANCE

The results from the ERS assessment show very little resistance values for both design options. The average resistance encountered along the corridor is 1.83 out of 5 and 1.94 out of 5 for the landscape-centered and grey infrastructure strategies respectively. However, the route along the grey infrastructure, in this case, the railroad tracks, is much more efficient in terms of distance covered, resulting in a significant decrease in cumulative resistance, being 421.6 for landscape-centered and merely 267.8 for the infrastructure-centered approach.

The grey infrastructure approach presents promising cumulative and mean resistance values. However, this strategy also encounters more local high-resistance areas. This is mostly caused by urban land cover, including the town of Borgo Vercelli, highway and provincial road intersections, and rural settlements. The landscape-centered approach encounters fewer of these high-resistance areas but due to the significantly greater distance, the cumulative values end up high.



CORRIDOR DESIGN

ASSESSMENT RESULTS

Design		Strategies minimum	
Cumulative resistance	424.2	278.8	Cumulative resistance
Mean resistance	1.84	1.83	Mean resistance
Median resistance	1.75	1.75	Median resistance
Overall distance	23.048 meter	22,209 meter	Overall distance

RESULTING DESIGN

An integrated design, combining the best-performing segments of both strategies is proposed in green. This design option eliminates the majority of these high-resistance areas while optimizing mean resistance values and covered distance.

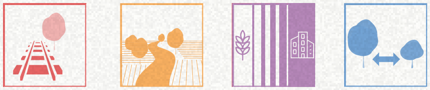
Disregarding the high-resistance points at infrastructural junctions and settlements, the alignment of the corridor to grey infrastructure turned out very efficient. This strategy is used as the foundation for the integrated design. The high-resistance areas are avoided as much as possible. However, not all of these bottlenecks can be averted.

The corridor has to cross the infrastructure itself on multiple occasions, as well as the A1 highway that needs to be crossed. These high-resistance points are unavoidable and form a barrier within the ecological landscape. Using the ERS, these locations are identified and can be selected for the implementation of creative design solutions, including ecoducts or wildlife crossings. The resulting resistance values from the design assessment are promising. Although the cumulative resistance value is higher than that of the infrastructure-based approach, the mean resistance values and the amount of high-resistance points have dropped significantly.

This results in the selected integrated design for the first segment of the green corridor. The other two segments are addressed before combining the different segments into a plan for the complete corridor path.


NOVARA
SESIA
RIVER
VERCELLI
N
0
1
2
4 KM


VIA ROMA
Sella
Sella

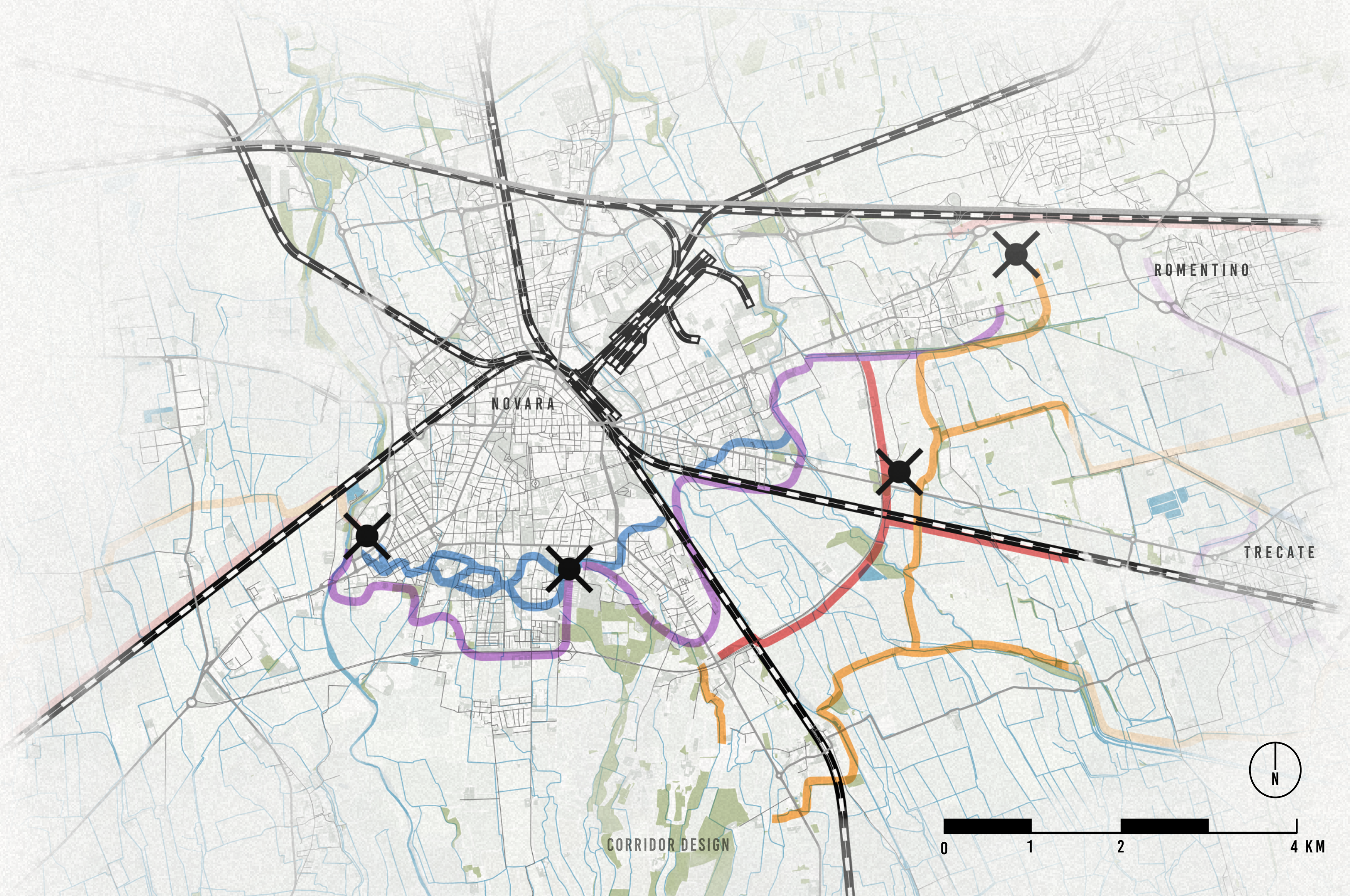


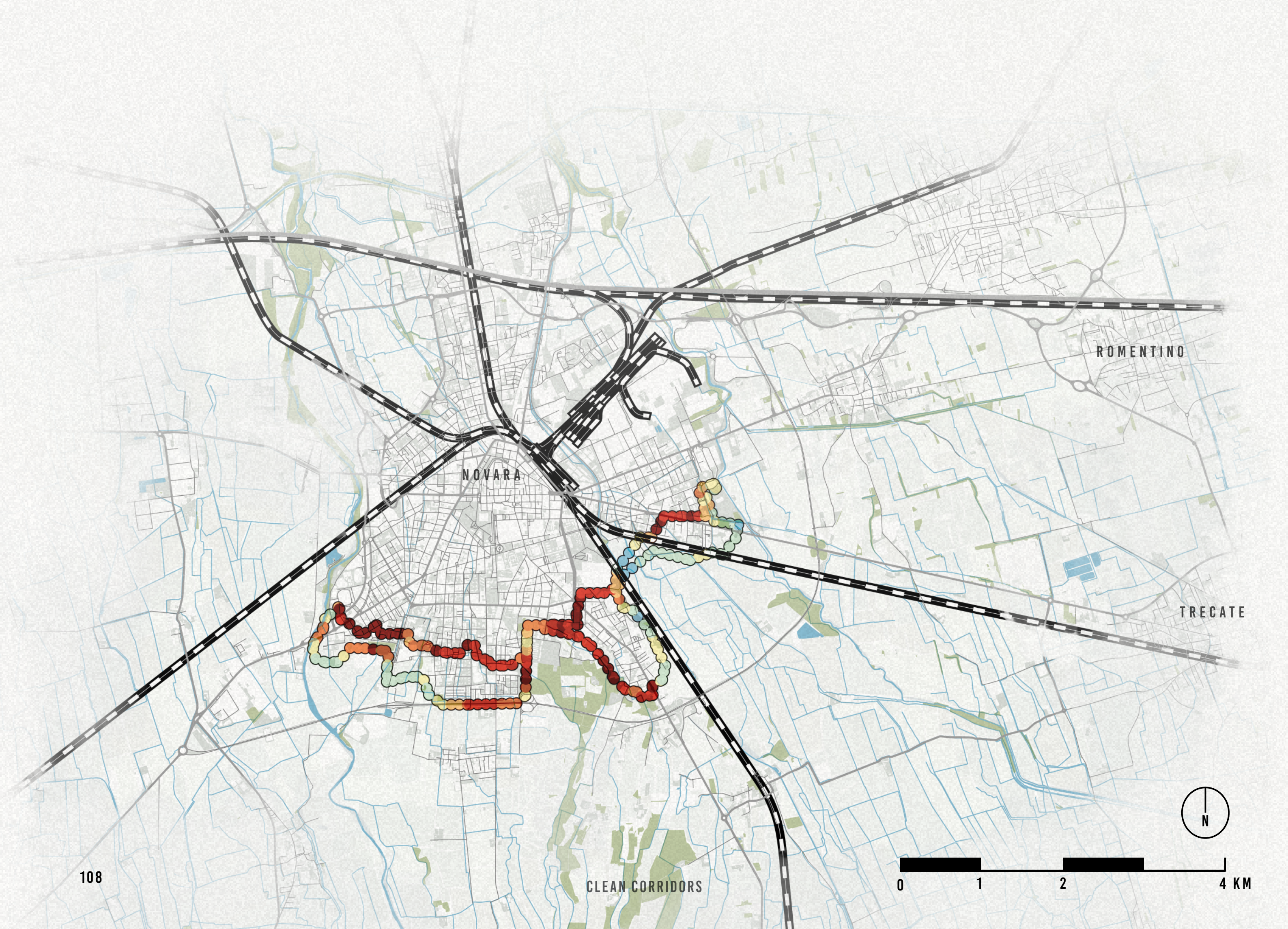
SEGMENT II - NOVARA SOUTH RING

The second segment from this corridor is formed by the southern ring of the city of Novara. This urban and peri-urban environment offers a lot of possibilities in terms of corridor design strategies and encompasses 4 remediation sites, all situated near the city's urban edge. As this segment hosts a lot of artificial land cover the ecological resistance values are quite high.

The route between the two westernmost remediation sites mostly covers urban land cover. Following the established strategies, two potential corridor paths appear. One route through the urban fabric, incorporating as many urban green elements as possible, and the other along the city's edges, using the open landscape bordering the city. Which one shows the most potential is determined using the ERS model.

In the eastern part of Novara, more strategies are suitable. Apart from the previous two options, this peri-urban landscape offers opportunities to follow the SS703 highway as an infrastructural guideline or use the forest south of the city to connect to the agricultural landscape. Although this area is more open, many infrastructural barriers in the form of railroads, highways, and provincial roads have to be crossed, presenting a lot of high-resistance areas.




NOVARA
ROMENTINO
TRECATE
N
0
1
2
4 KM

ISSUES AND RESULTING DESIGN

As this segment offers a lot of possible corridor paths, many calculations for the ERS assessment are needed. Therefore, this segment is again split into two parts.

The first part, in the southwest of the city, offers two options: covering a larger distance around the city with little resistance and a more distance-efficient path through the city, with relatively high resistance values. Cumulatively, these options do not differ that much from each other. However, the most potential for sustainable development lies not in choosing one option but in connecting the two strategies in an integrated way. This means creating peri-urban green elements that are well-connected and integrated into the urban green structure itself. The resulting integrated corridor design presents resistance values that are slightly better in comparison to the individual strategies. Additionally, the integration of peri-urban natural landscapes into urban green structures offers extra benefits in terms of mental health and improved urban biodiversity.

The second segment forms a larger peri-urban landscape, allowing for multiple design options to be created. Again, two options are assessed: one going primarily through the urban context, the other through the more rural landscape, using infrastructural and landscape features as guides. Although, the average resistance values in the natural landscape are very low, the excessive distance that has to be covered results in high cumulative resistance values. The urban option is far more efficient but would require intensive ecological enhancements in the urban green structure, including the incorporation of greenery in the street profiles, densely vegetated parks, and natural road verges. Although a big investment, this has a lot of co-benefits on the urban climate and human well-being.

The resulting integrated design is a combination of urban and peri-urban green structures. Although not all elements of the corridor path are optimized for ecological resistance, they offer a lot of co-benefits for humans and ecosystems.

ASSESSMENT RESULTS

Strategy 1 – Urban/Rural Gradient

Cumulative resistance	263.3
Mean resistance	3.1
Median resistance	2.8
Overall distance	8,522 meter

Strategy 2 – Urban green structure

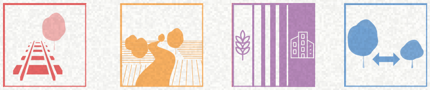
209.6	Cumulative resistance
4.0	Mean resistance
4.1	Median resistance
5,214 meter	Overall distance

Design

Cumulative resistance	157.6
Mean resistance	2.7
Median resistance	2.3
Overall distance	5.834 meter

ASSESSMENT RESULTS

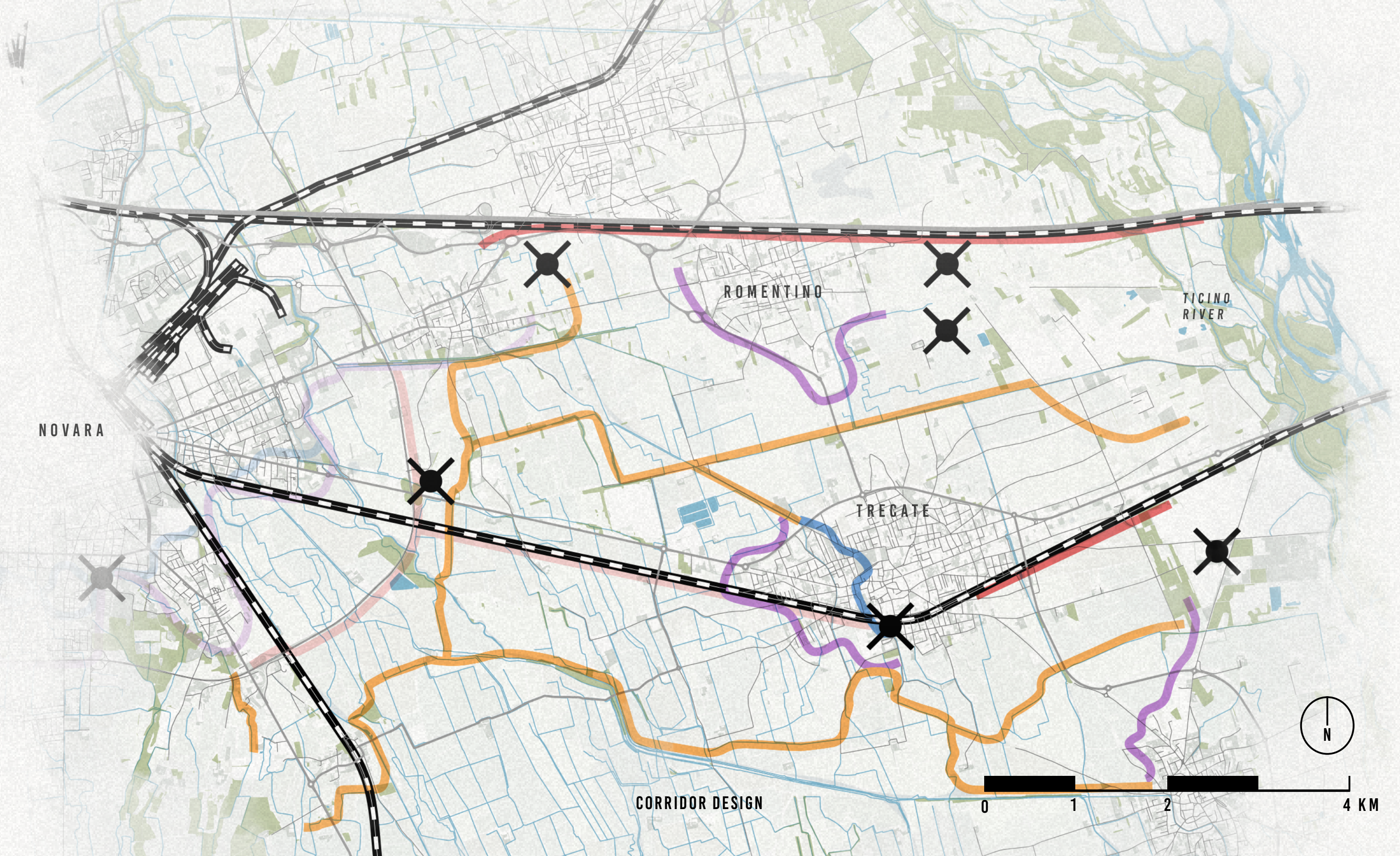
Design		Strategies minimum	
Cumulative resistance	157.6	209.6	Cumulative resistance
Mean resistance	2.7	3.1	Mean resistance
Median resistance	2.3	2.8	Median resistance
Overall distance	5.834 meter	5,214 meter	Overall distance



SEGMENT III - TOWARDS THE TICINO

The easternmost segment of the corridor is situated between the city of Novara and the Ticino Valley Natural Reserve. The area is mostly rural, but is nestled in between the urban areas of Novara, Pernate, Trecate en Romentino. As the remediation sites are more dispersed in the landscape the corridor is likely The easternmost segment of the corridor is situated between the city of Novara and the Ticino Valley Natural Reserve. The area is mostly rural but is nestled in between the urban areas of Novara, Pernate, Trecate, and Romentino. As the remediation sites are more dispersed in the landscape the corridor is likely to have multiple branches. The agricultural areas are occupied with irrigation channels and canals, which can guide the green corridor. At the same time, two major railroad connections and the A4 highway offer opportunities for designing infrastructure-based corridor paths.

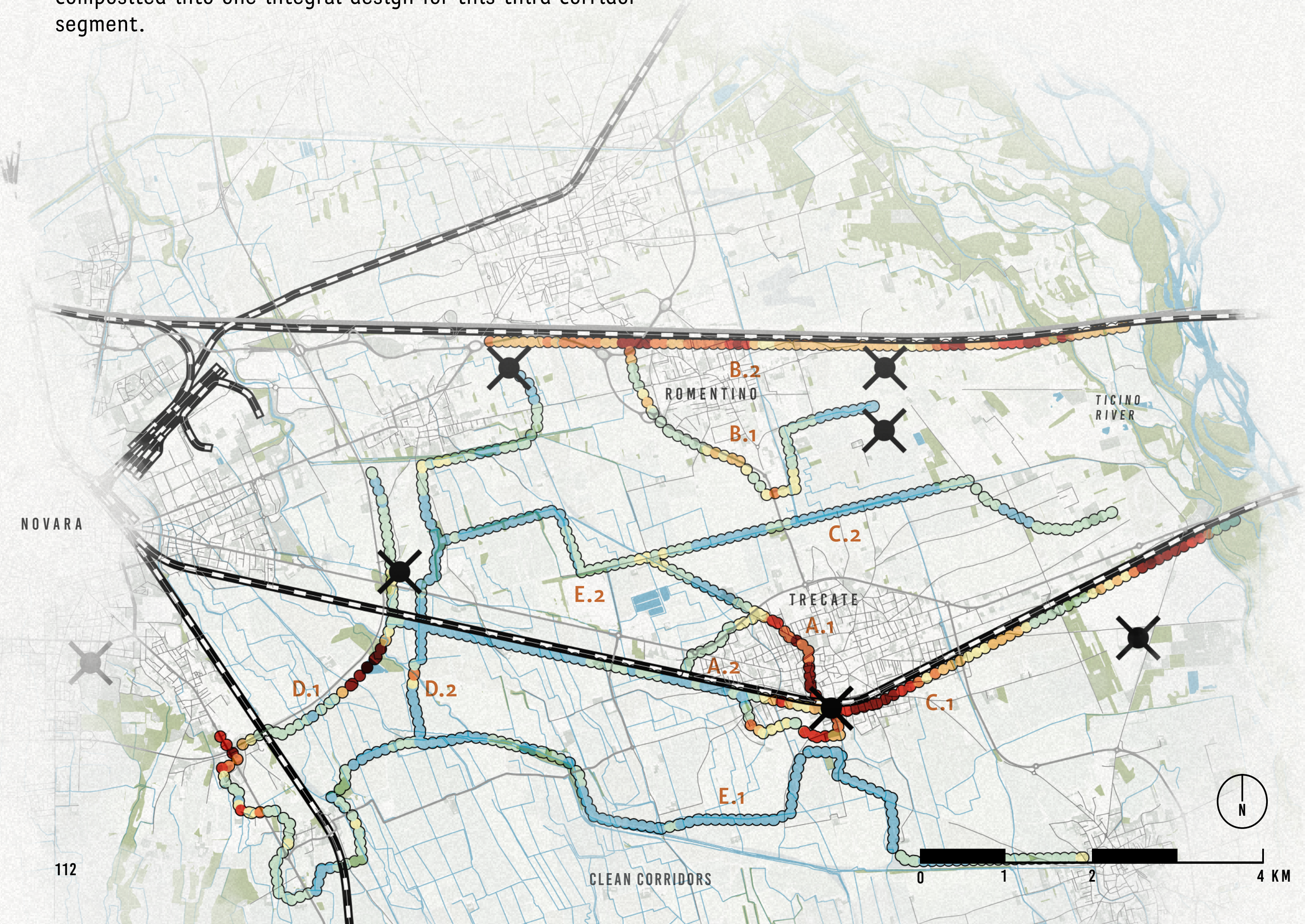
The urban cores of Trecate and Romentino are positioned in such a way that they have to be crossed by the corridor path. These are the areas with the highest resistance within this segment. The surrounding area is primarily used for agriculture and industrial activities, leaving sparse room for natural vegetation. The resulting design specifically aims at the integration of these rare green elements.



MAJOR ISSUES

As this segment is branched to be able to incorporate as many contaminated sites as possible, a variety of options appear. The decision-making process is segmented into 5 parts (A-E), each with two design options. The segments are shown in the map below, with the corresponding ERS results on the following page. For each of these parts, the best-performing option is selected. The selected options are then composited into one integral design for this third corridor segment.

As visible in the map below, again there is a competition between distance-efficiency and the minimization of faced resistance. Especially around the town of Trecate and along the railroads in Romentino, high-resistance areas are present. The ERS results will present the best options.



ASSESSMENT RESULTS

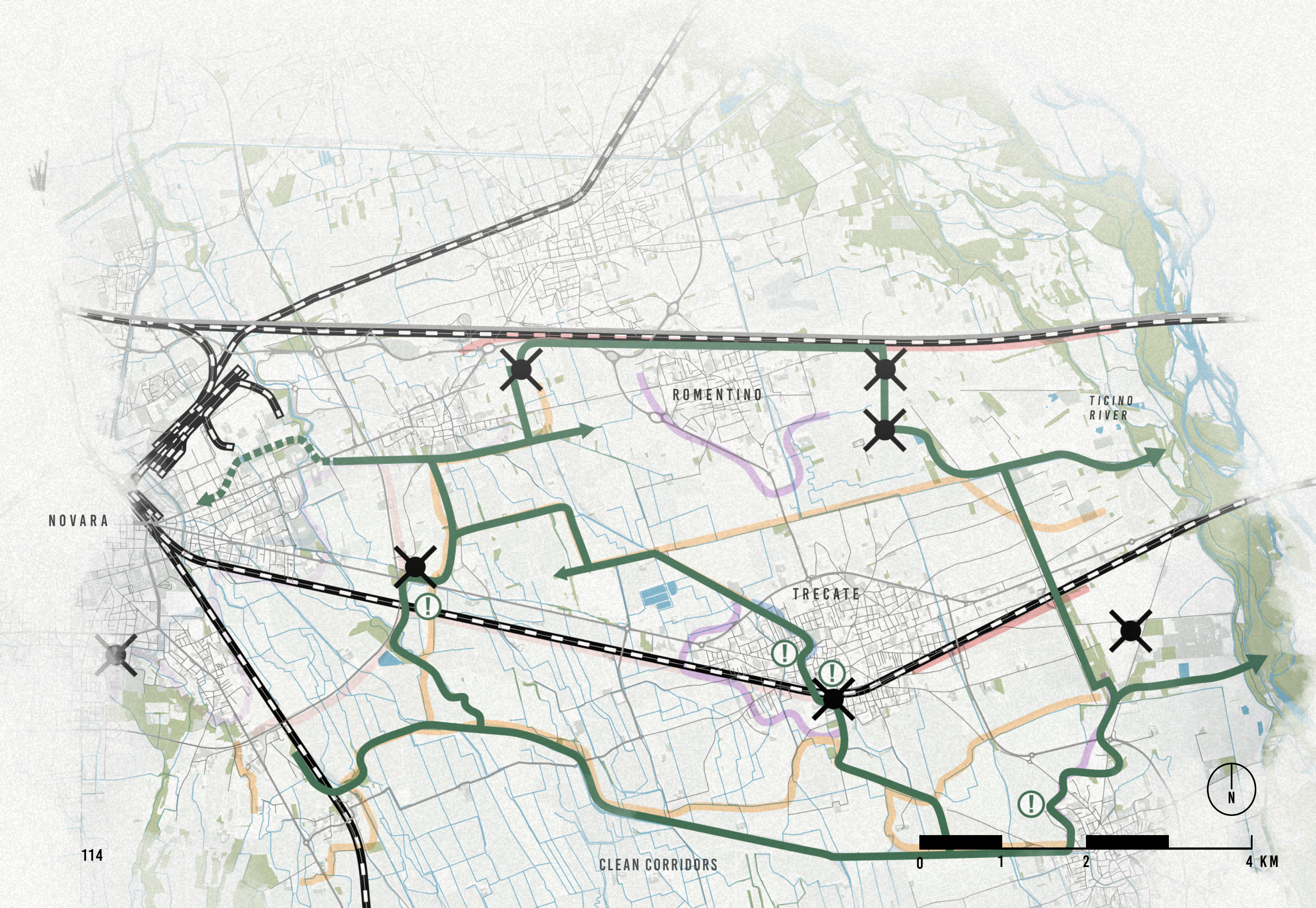
	Strategy A.1 – Urban Green Structure	Strategy A.2 – Urban-Rural Gradient
Cumulative resistance	92.5	145.0
Mean resistance	4.0	2.7
Median resistance	4.1	2.4
Overall distance	2,314 meter	5,369 meter

	Strategy B.1 – Urban-Rural Gradient	Strategy B.2 – Grey Infrastructure
Cumulative resistance	168.3	234.3
Mean resistance	2.5	3.5
Median resistance	2.3	3.4
Overall distance	6,730 meter	6,695 meter

	Strategy C.1 – Grey Infrastructure	Strategy C.2 – Landscape Centered
Cumulative resistance	422.9	166.1
Mean resistance	2.8	2.0
Median resistance	2.3	2.0
Overall distance	15,105 meter	8,307 meter

	Strategy D.1 – Grey Infrastructure	Strategy D.2 – Landscape Centered
Cumulative resistance	162.4	172.2
Mean resistance	2.7	2.1
Median resistance	2.3	2.0
Overall distance	6,016 meter	8,201 meter

	Strategy E.1 – Landscape Centered	Strategy E.2 – Urban green structure
Cumulative resistance	286.7	368.5
Mean resistance	2.3	2.6
Median resistance	2.0	2.0
Overall distance	12,466 meter	14,174 meter



CLEAN CORRIDORS

RESULTING DESIGN

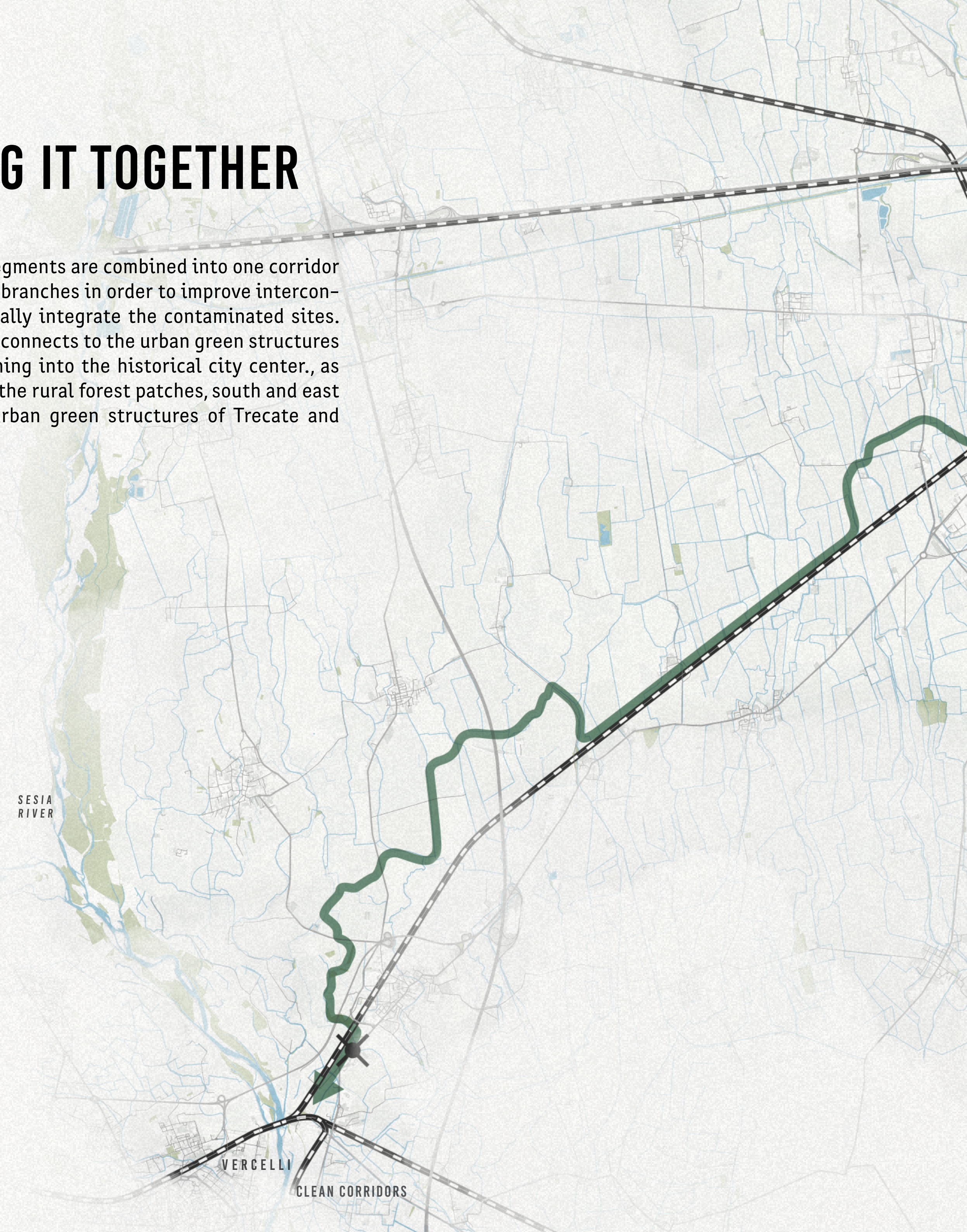
The northern corridor path follows the highway and railroad tracks between Novara and Milano. This area offers a very high ecological resistance since the area is densely built, has a lot of infra-structure, and is very sparsely vegetated. However, the distance is very short and the proposed corridor serves as a multi-mechanism buffer between the town of Romentino and the A4 highway. Currently, the town is located directly bordering the railroads and highway, buffering the airborne pollution and creating a visual and noise barrier between the infrastruc-ture and the town improves living condi-tions within the town.

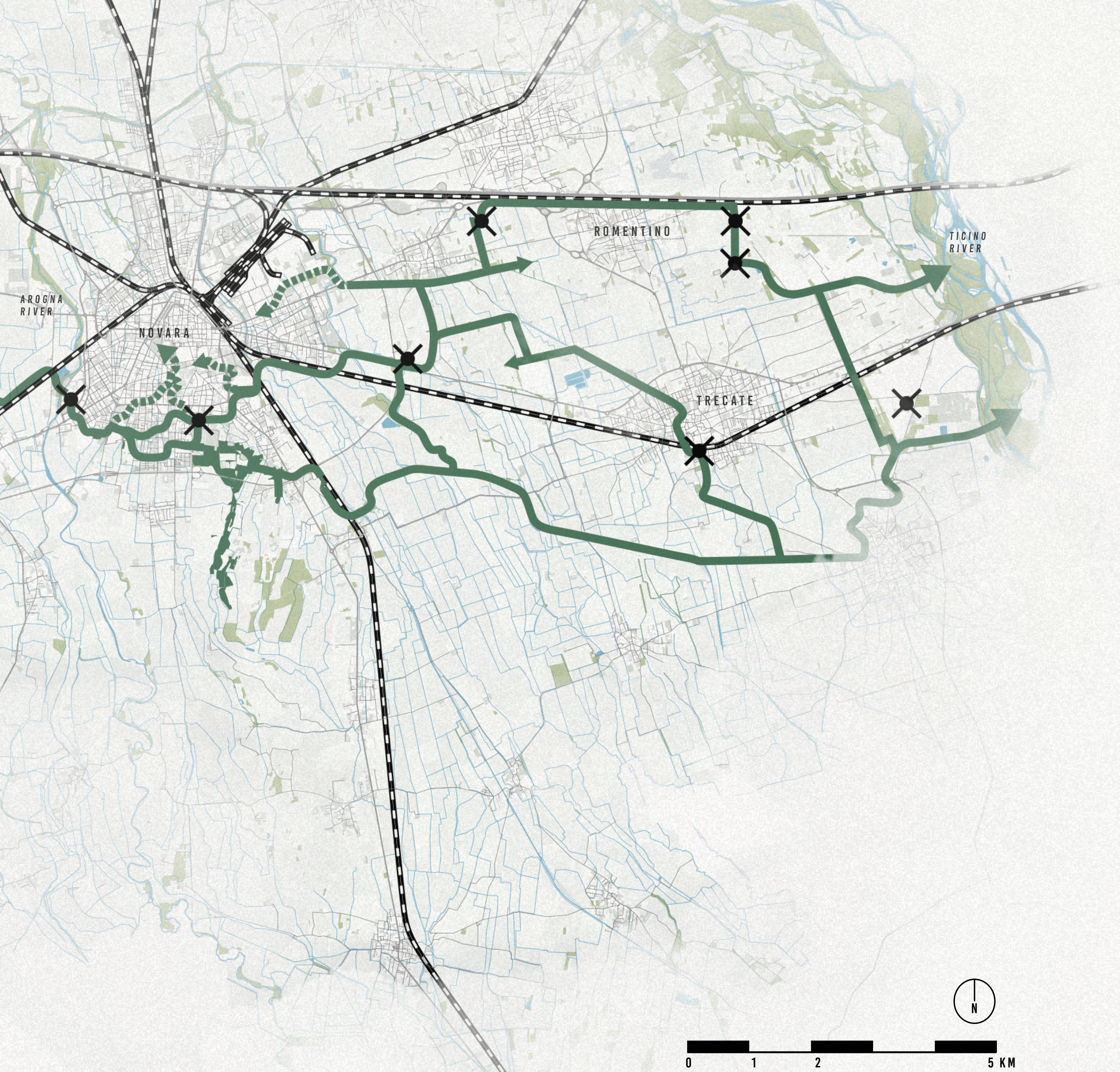
The rare existing green patches between Pernate and Trecate, mainly along the major irrigation channels are incorporated into the green structure. Connecting this to the urban green structure within the urban fabric of Trecate offers a better connection to the landscape and improves the living quality in the currently quite imperviously built town.

The Integrated design options covers the entire landscape between Novara and the Ticino River. Throughout the land-scape, existing forest patches and urban green elements are incorporate in the GI, creating a strong and resilient network.

STITCHING IT TOGETHER

The three different segments are combined into one corridor with multiple smaller branches in order to improve interconnectivity and holistically integrate the contaminated sites. The regional corridor connects to the urban green structures of Novara, even reaching into the historical city center., as well as incorporating the rural forest patches, south and east of Novara, and the urban green structures of Trecate and Romentino.

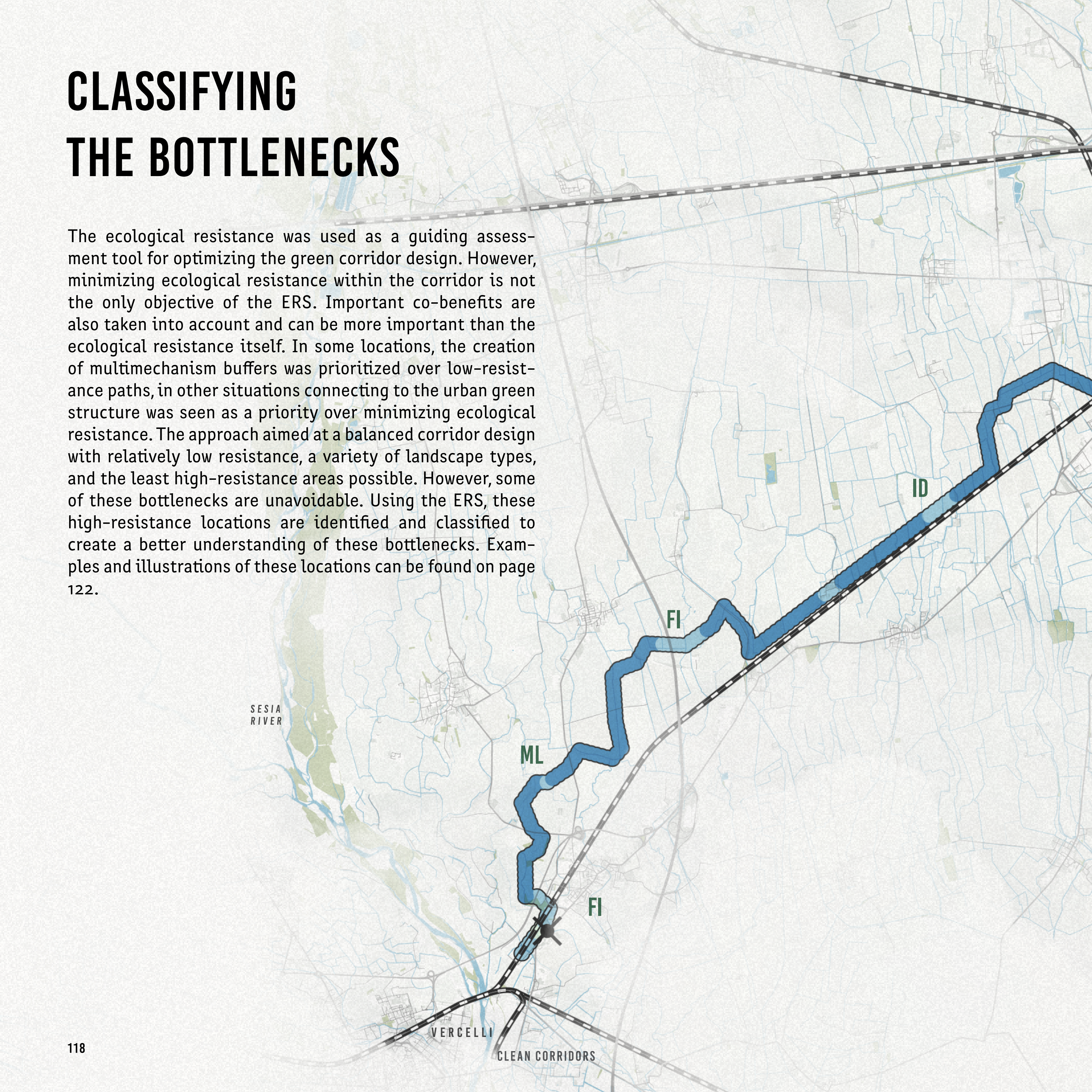


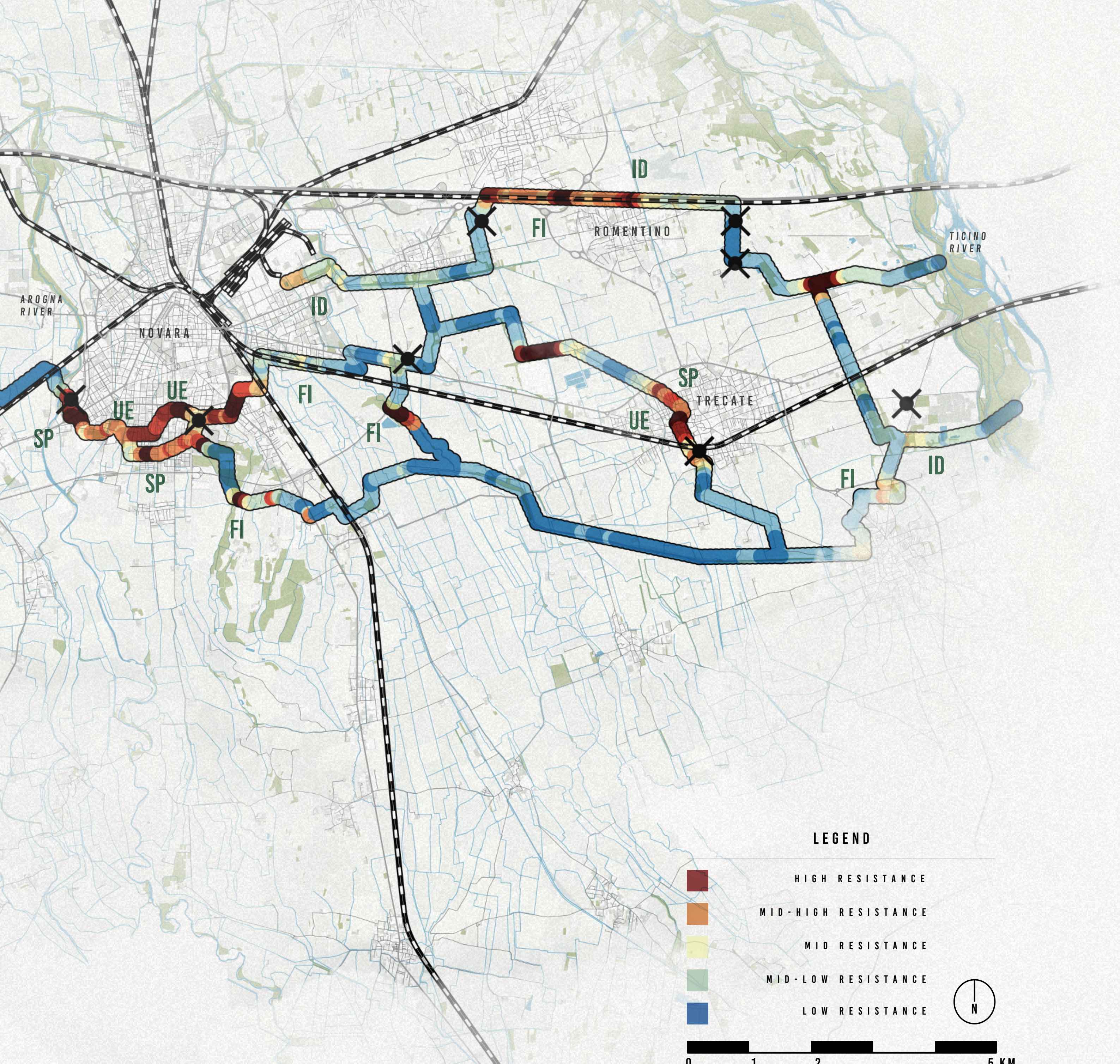


CORRIDOR DESIGN

CLASSIFYING THE BOTTLENECKS

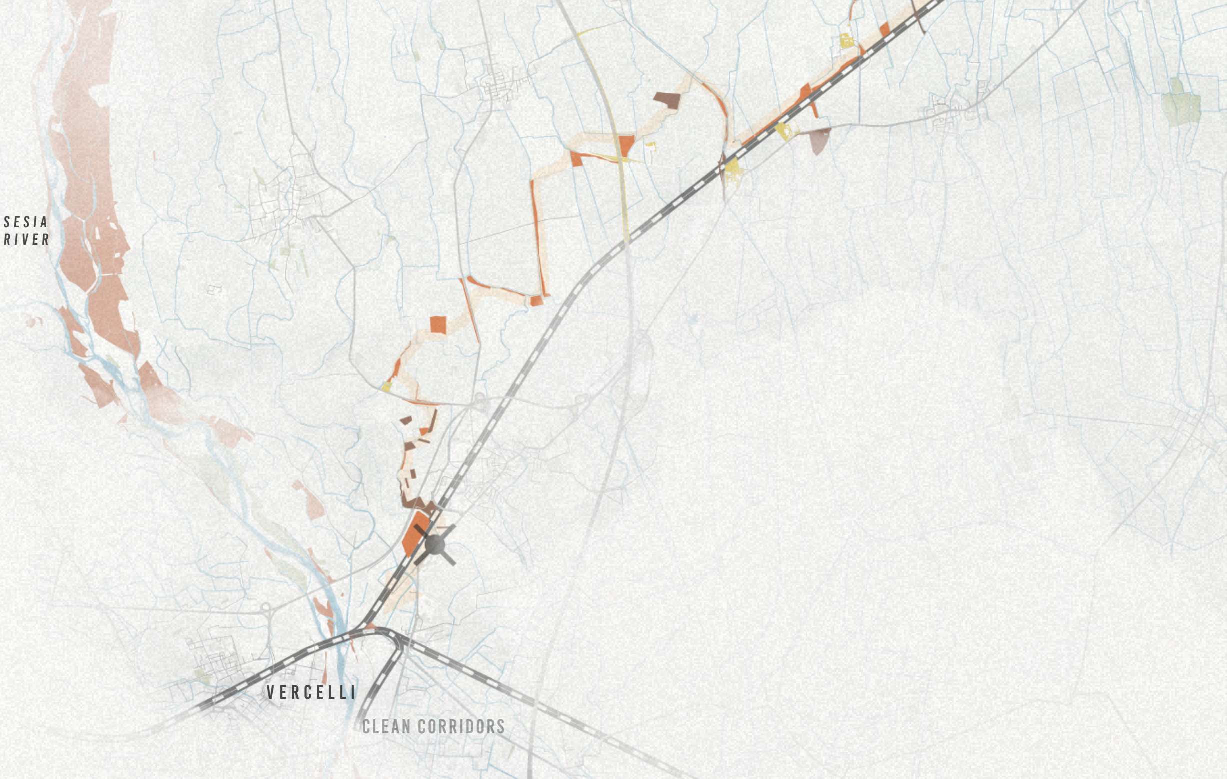
The ecological resistance was used as a guiding assessment tool for optimizing the green corridor design. However, minimizing ecological resistance within the corridor is not the only objective of the ERS. Important co-benefits are also taken into account and can be more important than the ecological resistance itself. In some locations, the creation of multimechanism buffers was prioritized over low-resistance paths, in other situations connecting to the urban green structure was seen as a priority over minimizing ecological resistance. The approach aimed at a balanced corridor design with relatively low resistance, a variety of landscape types, and the least high-resistance areas possible. However, some of these bottlenecks are unavoidable. Using the ERS, these high-resistance locations are identified and classified to create a better understanding of these bottlenecks. Examples and illustrations of these locations can be found on page 122.

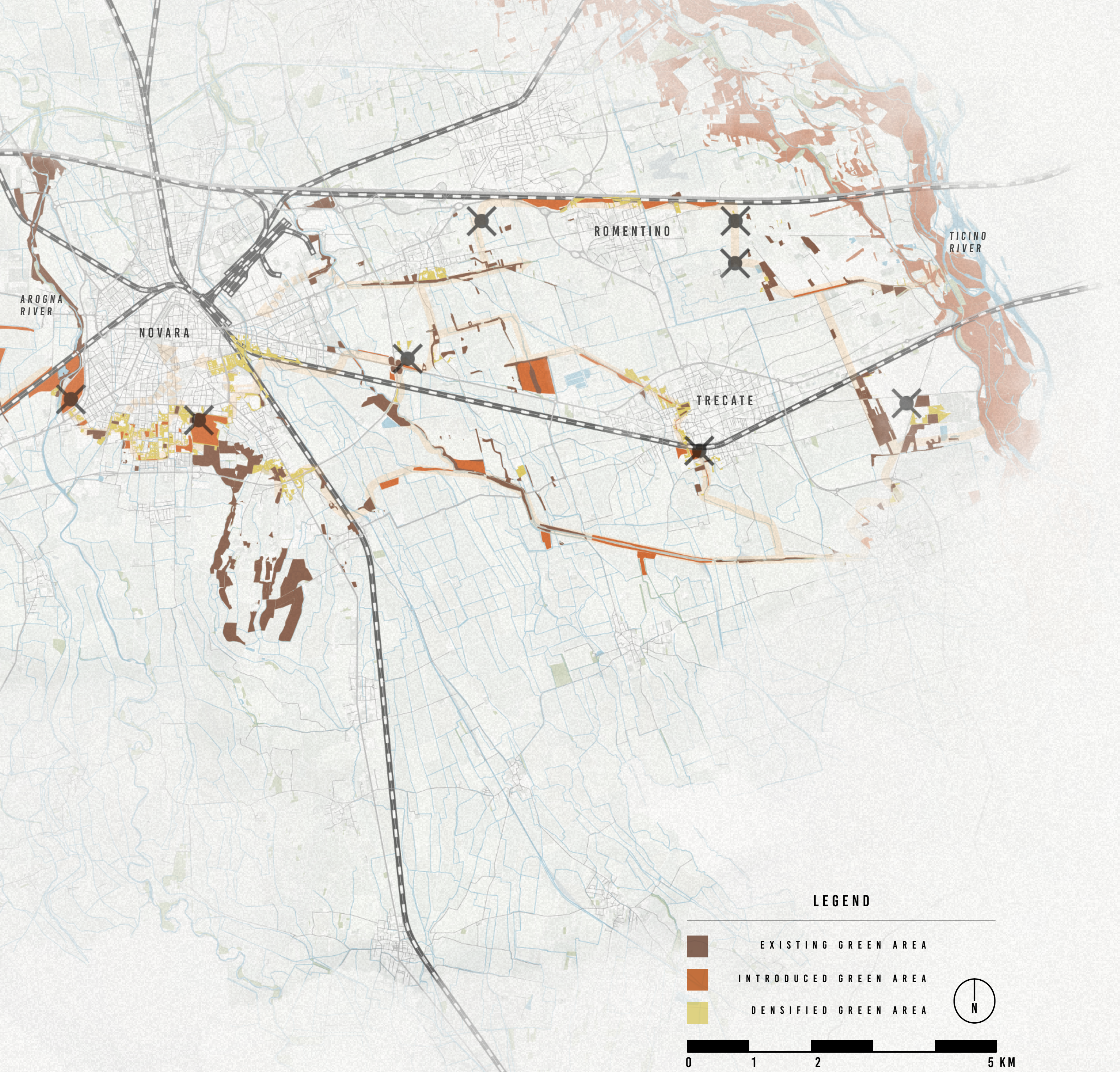



ID
FI
ROMENTINO
TICINO RIVER
AROGNA RIVER
ID
NOVARA
SP
FI
TRECATE
UE
UE
FI
UE
SP
SP
FI
ID
FI
LEGEND
HIGH RESISTANCE
MID-HIGH RESISTANCE
MID RESISTANCE
MID-LOW RESISTANCE
LOW RESISTANCE
N
0
1
2
5 KM

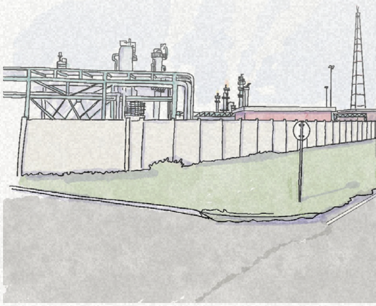
FROM LINES TO SHAPES

Until now corridor planning has exclusively focused on corridor paths and routing. Testing, assessing, and refining corridor paths help create a general plan for the implementation of new corridors and allow quick calculations on functionality and resistance. However, GI is not a linear two-dimensional element. The proposed corridor path is transformed into connected patches, varying between linear riparian zones, dense forest patches from transformed agricultural fields, multimechanism buffers, and linear urban green structures incorporated in the street profiles. During the design process, the patches and their connections were designed using the same dispersal distances applied in the Conefor strategy. This ensures the interconnectivity of the patches and their contribution to the landscape connectivity.

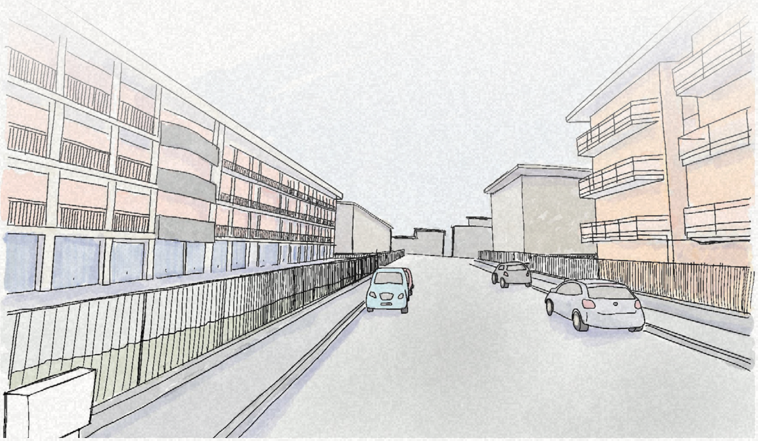



ROMENTINO
TICINO
RIVER
AROGNA
RIVER
NOVARA
TRECATE
LEGEND
EXISTING GREEN AREA
INTRODUCED GREEN AREA
DENSIFIED GREEN AREA
N
0
1
2
5 KM

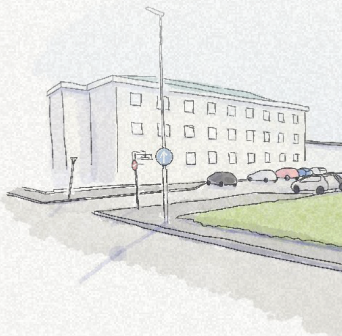
FRAGMENTING INFRASTRUCTURE FI



INDUSTRIAL DISRUPTION

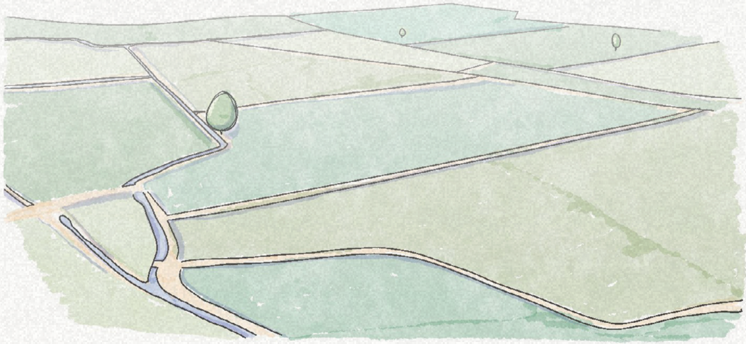


GREY STREET PROFILES SP



LACK OF URBAN ECOLOGY

ID



MONOTONY IN THE AGRICULTURAL LANDSCAPE ML

UE

REMAINING ISSUES AND BOTTLENECKS

The remaining bottleneck can easily be classified into five categories: fragmenting infrastructure (FI), industrial disruption (ID), monotonous landscapes (ML), grey street profiles (SP) and the lack of urban ecology (UE). The issues relating to high ecological resistance values are visualized here. Spatial design interventions, including ecoducts, agroforestry principles, hedgerows, green street profiles, vegetation buffers, and enhanced riverbeds can be used to overcome these ecological issues.

LANDSCAPE VARIATION

Landscape heterogeneity, characterized by diverse land cover types, topography, and spatial arrangements, influences the functioning of ecosystems (Turner, 2005). Research has shown that landscape diversity positively impacts ecological processes such as nutrient cycling, soil erosion, and biodiversity maintenance (Chen et al., 2009). Besides that, compositions of different forest types, landscapes, and plant species are proven to enhance ecosystem resilience, contributing to both ecological and economic stability (Turyasingura et al., 2022).

It is important to design with this information in mind. Designing one extensive corridor, following a straight path, with one fixed width, and using a predefined set of plant species admittedly connects multiple habitat patches, but is still vulnerable to disruption of its ecosystem.

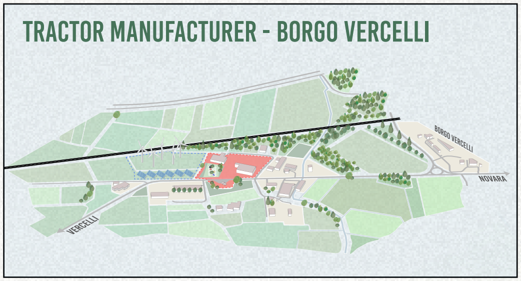
CORRIDOR CONCLUSIONS

Using the ERS model helps design functional routes for GI and ecological corridors. Although a helpful tool, implementation of the ERS is not always leading. Other implications and objectives need to be taken into account when designing. The ERS is merely calculating the resistance within the corridor itself but does not consider the corridor's impact on the surrounding landscape. Placing the corridor along grey infrastructure as a form of vegetation buffer has a lot of positive effects on the surrounding landscape for example. However, the ERS would advise against the placement of green structures in that specific location.

Additionally, other landscape properties, including habitat patch variation, corridor width, and current land use need to be taken into consideration. All in all, the use of ERS and predefined strategies have been helpful tools for creating a well-functioning regional corridor.

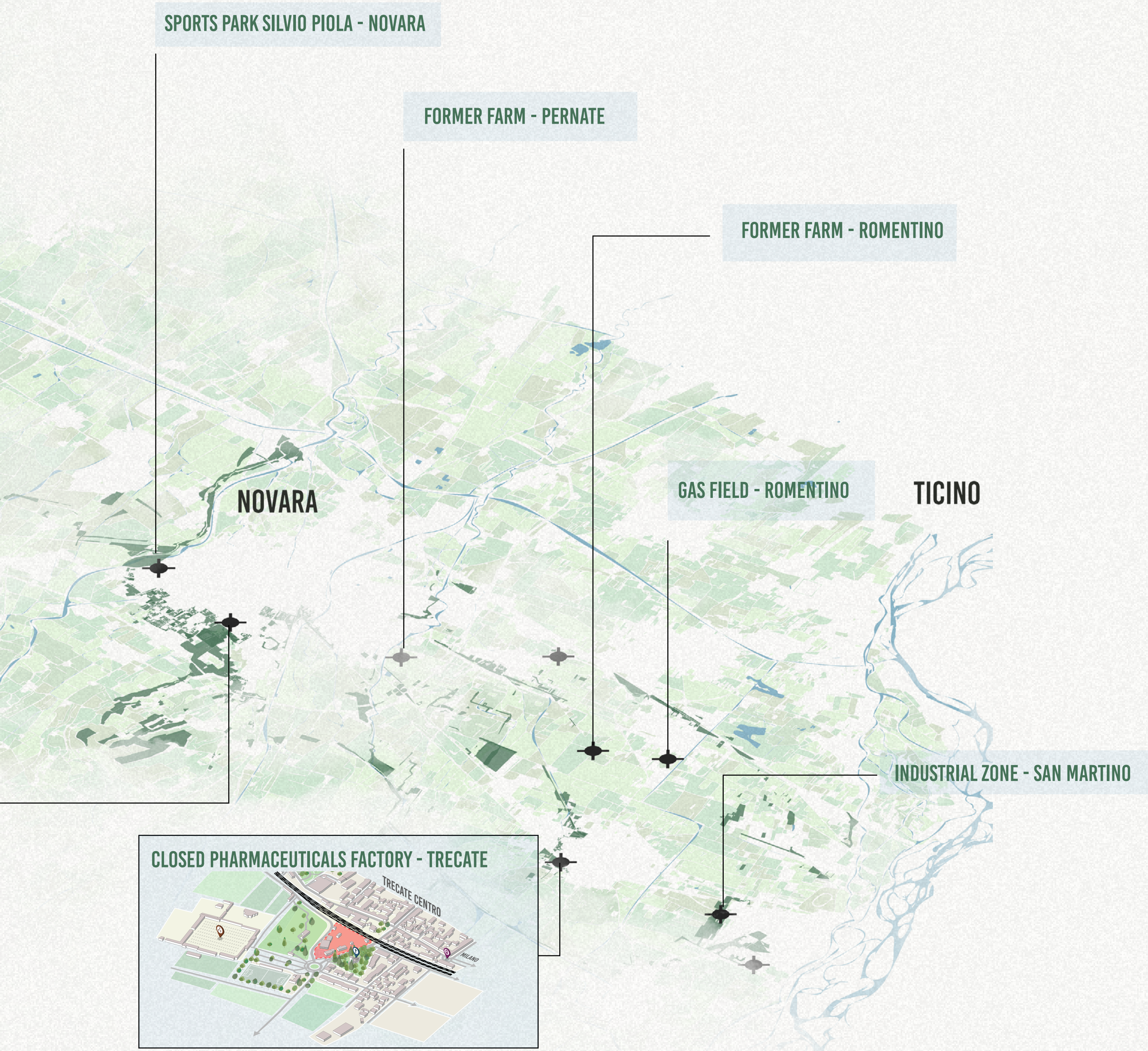
With the corridor path designed, it is time to take a closer look at the integration of contaminated sites. The next chapter dives into redesign strategies for the contaminated sites along the corridor route and aims at the implementation of remediating vegetation that can connect to the green corridor.

05 CONTAMINATED SITES



INTEGRATION OF REMEDIATION SITES

Until now we have only spoken about ways to connect the different remediation sites using GI. However, the contaminated sites themselves have to be redesigned for phytoremediation and other nature-based solutions to become functional. The applied phytoremediation plants help clean the soil but form an essential part of the green structure as well. In the following pages, we delve into the contaminated sites that are present within the study area and define a framework for the sustainable redesign of these sites. This map shows an overview of the contaminated sites that are included in the regional corridor design. A parcel of a tractor manufacturer in Borgo Vercelli and a closed pharmaceutical factory in Trecate will be used as showcase locations for the developed design framework.


SPORTS PARK SILVIO PIOLA - NOVARA
FORMER FARM - PERNATE
FORMER FARM - ROMENTINO
NOVARA
GAS FIELD - ROMENTINO
TICINO
INDUSTRIAL ZONE - SAN MARTINO
CLOSED PHARMACEUTICALS FACTORY - TRECATE
TRECATE CENTRO
MILANO

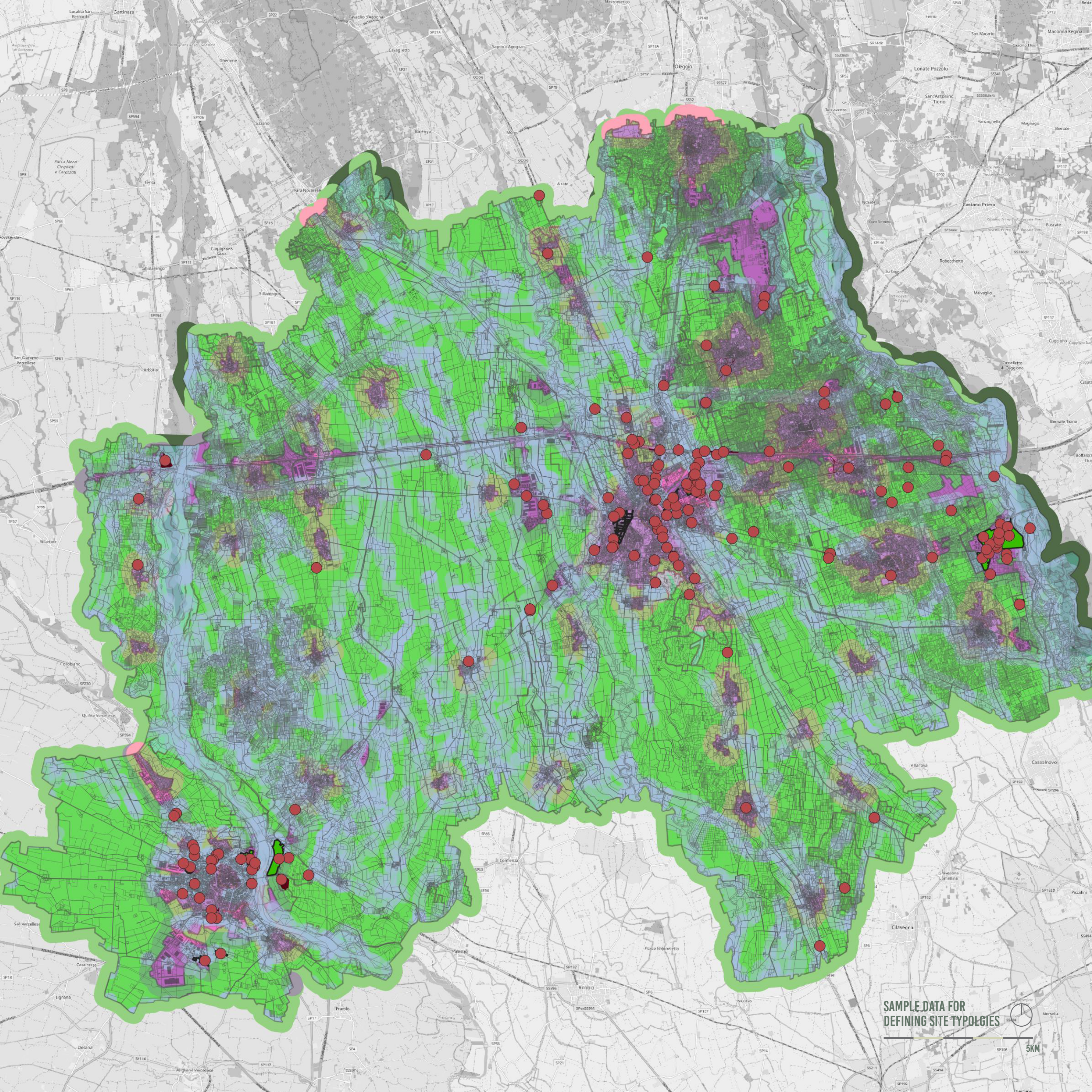
DEFINING TYPOLOGIES - ANALYSIS & CLUSTERING

WHY DO WE NEED TYPOLOGIES?

We are taking a step back from the design table and heading into the data again. When looking at the direct surroundings of Novara, we find 171 sites that are marked by the Piedmont region and the Italian Institute for Environmental Protection and Research (ISPRA) as contaminated and in need of remediation. These contaminated sites are all located in an area of no more than 832 square kilometers. This means that there is a contaminated site in approximately every 5 square kilometers. Redesigning every single one of these sites is inefficient and not feasible. Each site is unique and has its own set of variables. Sites differ in terms of contaminant, contaminant type, contaminant concentration, contaminant depth, cause of contamination, plot size, land use, surrounding context, state of operability, the presence of structures or buildings, and many more. However, we don't have to reinvent the wheel for every contaminated site. By creating typologies of these different sites we can create a framework for redesigning and redeveloping these areas. By designing strategies and design guidelines for the site typologies, we can apply similar design methods over and over again without having to start from rock bottom.

The typologies are defined by looking at a variety of spatial data. As the implementation of phytoremediation and nature-based solutions is extremely specific and requires a thorough examination of the site, this is not possible to include in the typology classification. The vegetation that is to be chosen in phytoremediation is based on contamination types, climate variables, soil state, etc. Performing these types of analyses for all the sites is impossible and not useful. We can create typologies based on spatial arrangements though. Using data on plot size, state of operability, the presence of structures, land use, and context results in typologies that have similar spatial features. These spatial features can then be translated into spatial design interventions which include space for the implementation of phytoremediation. The exact type or species of remediation plants are not selected in this phase yet. However, certain requirements for those plant species, such as growth rate, growth habit, size, and sowing regime could be stated.

For the typology selection, four different variables are selected: plot size, presence of buildings or other structures, land cover type, and the operability of the site. Using QGIS, this data is sampled from the different data layers. The used data is all derived from openly accessible sources. The Corine Land Cover 2018 is used to determine the local land cover types, cadastral data from the Piedmont region is used to calculate the plot size, and regional spatial planning data is used to determine the presence of structure on the cadastral plots that host the contamination. Although in most places available and accessible, the data on the operable state of the different sites was not available for the research area. However, this data is essential for typology and strategy creation. Operative sites and sites that have to keep functioning the way they do, also during and after remediation practices, offer very few possibilities for redevelopment compared to sites that are not in use anymore and can be transformed into new functions. The next pages are dedicated to the data gathering for the operability state of the sites.



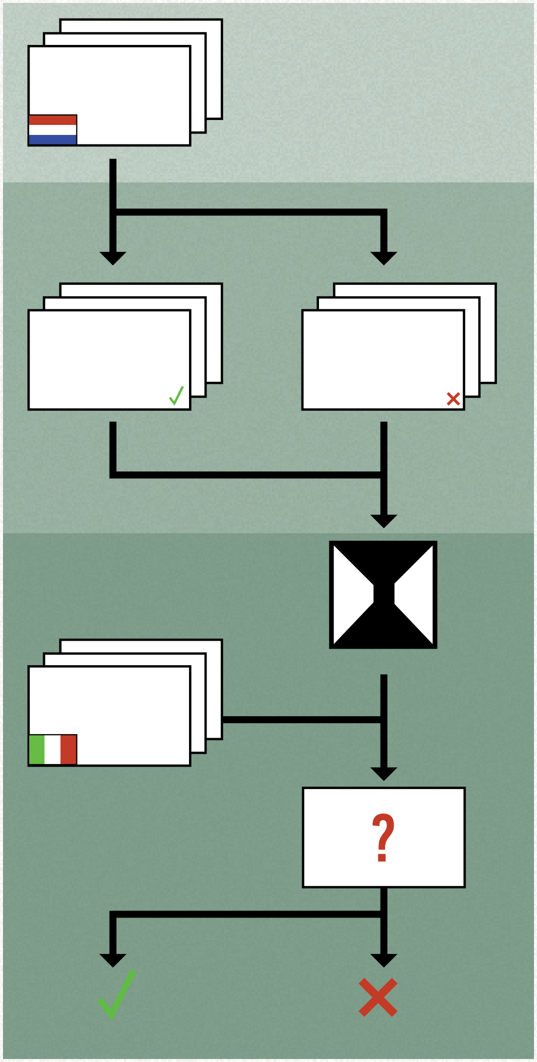
SAMPLE DATA FOR
DEFINING SITE TYPOLGIES
5KM
Oleggio
Lonate Pozzolo
Castano Primo
Robbio

OPERABILITY ASSESSMENT USING CNN

Artificial intelligence (AI) and Machine Learning have become an important part of society over the last few years. Workflows using AI are integrated into increasingly more work fields and the possibilities and accuracy of AI software are growing by the day. One of the better-known applications of convolutional neural networks (CNN) is in object and image recognition. By creating a CNN in Python using Tensorflow, that is trained on the recognition of abandoned and unused structures, it is possible to map the operability of all contaminated sites within the study area.

For this to work I still need to have images of the contaminated sites that I want to classify. Making physical trips to all the contaminated sites and capturing the images physically takes a significant amount of time and effort. Instead, Google Street View is used to get imagery of the sites. Using the Google Maps Static API and Python makes it even easier to get imagery for my sites. Using the coordinates from the sites that I gather using GIS, I can request the imagery from Google Street View of these sites and feed those images into my neural network for classification.

However, neural networks have to be trained to be able to function. The neural networks need to be fed a lot of example images that are already classified as operable and inoperable to be able to decide if the cases in my study area are still in operation or not. As the images I'm going to be using are all imagery from Google Street View, the best training data would be imagery from Google Street View as well. I used the Basisregistratie Adressen en Gebouwen (BAG), the Dutch data on buildings en addresses. In contrast to the Italian data for my research area, this dataset does come with data on the state of operability. The coordinates of 7,186 Dutch operable and 7501 inoperable buildings were extracted. Using Phyton and the Google Maps Static API, I tried to download all the images for these structures. As not all locations had adequate imagery, this resulted in 4,340 images of operable and 2,345 images of inoperable buildings. These images were used to train the CNN so it could classify the cases within my actual study area. The estimated data gathered with the CNN is then added to the geodatabase with the other site variables and is ready to be analyzed. A simplified diagram shows the use of the CNN. Images on the right show some results of the CNN in the study area.




INACTIVE
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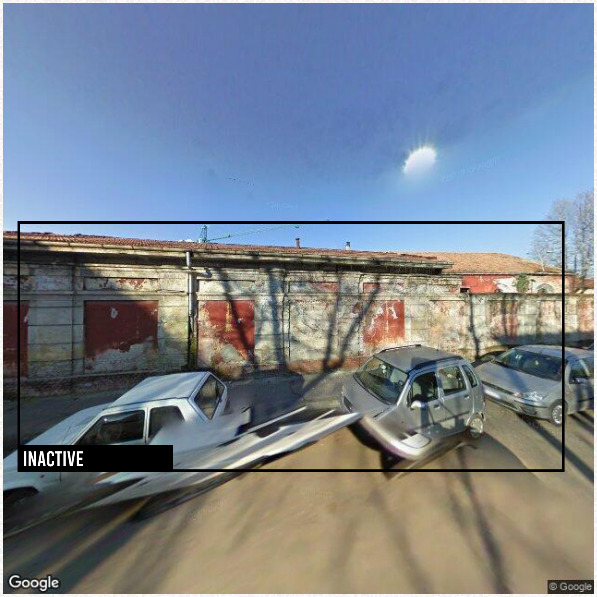
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FLAWS AND IMPROVEMENTS

The images from the Dutch cases were used to train the neural network to detect inoperable buildings. After training the CNN achieved accuracies of 64% and 80% for validation and training data. This means that when confronted with new data, the accuracy of the CNN estimation is around 64%. This is not remarkably high. CNN, when trained adequately can reach accuracies of almost 99%. However, this takes a lot of time and a lot of high-quality input data. Since the CNN is just a tiny element in this thesis, no more effort was put into improving the accuracy of the model.

Various flaws in this methodology need to be mentioned. Firstly, the CNN is trained on data on buildings, this means that is only capable of identifying abandoned or inoperable buildings. The contaminated sites, however, do not necessarily need to have structures on them. Some of the contamination sites are agricultural fields for example, or barren plots with already demolished structures. Since the CNN is not trained for this, it does not know how to classify them, resulting in inaccurate results.

Secondly, since the imagery is automatically gathered from Google Street View, there is no supervision of the input data. Sometimes the gathered imagery does not show the actual structure or remediation site but focuses on the public space, sometimes there are multiple structures visible, and the CNN does not understand which of these is the selected site, or structures are hidden behind vegetation or fences, unable to be identified by the CNN. Google Street View uses stitched images made from moving vehicles. This often results in motion blurs and artifacts within the images. This is also something that sets off the CNN.

Lastly, as the training data is taken from another country, the CNN can be a bit unreliable. As the surrounding landscape, building architecture, and cultures differ between the sites the CNN can make wrong decisions. Sites that look abandoned in the Netherlands look different than those in Italy.

The approach of using the CNN is still very biased and inaccurate. Although not ready for practical applications yet, this approach has a lot of potential. Being able to use elsewhere applicable data to bridge (or better, estimate) local data gaps using AI offers interesting opportunities. When trained properly and applied with careful consideration to its possibilities and limitations, this approach can be useful for spatial planning and other work fields.


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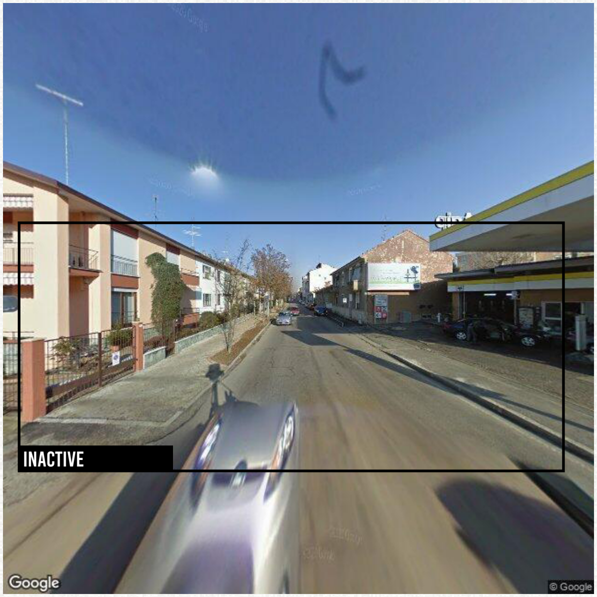
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K-MEANS CLUSTERING

To generate typologies from this database on the contaminated sites a k¬-means cluster analysis is performed. K-means clustering is a method that was originally used in signal processing to group and categorize transmission signals but is now more widely used in other forms of data science. K-means analysis aims to partition data points, carrying multiple types of information, into a predetermined number of partitions (or clusters) of data points with similar characteristics. K-means clustering is one of the most accessible and popular machine learning algorithms. One characteristic of this type of clustering is that it is unsupervised. This means that the classification of these sites is not based on predetermined categories, but rather uses similarities in the data to establish these classes.

For this application k-means clustering is used on the sampled data from the contaminated location in the direct surroundings of Novara. Using the clustering methods, results in more targeted design strategies that better suit the found sites. Instead of making redevelopment strategies categorized on land use of plot size, this approach reveals the patterns of those sites.

The data used for this clustering has four variables: land-use type, plot size, presence of structures or buildings, and operability of the site. Based on the elbow method an optimal amount of 5 clusters is determined. This means that if more clusters were made, the values of these clusters would be fairly similar, resulting in typologies that resemble each other a lot. Fewer clusters would result in a lot of variation between the sites belonging to the same cluster, which results in inaccurate targeting and strategies that would not fit the actual contaminated sites.

The results from the clustering are shown in the table. The following pages delve deeper into the results of the individual clusters to derive a typology out of the resulting cluster.

CLUSTERTYPE 1	MEAN	MEDIAN	MODE	URBAN INCIDENTS
Structure	0	0	0	no structure
Plot size	2404.366667	1093	–	square meters
Context	2.2	2	2	urban context
Operability	0.533333333	1	1	mostly operable
CLUSTERTYPE 2	**MEAN**	**MEDIAN**	**MODE**	**SMALL INDUSTRIES/COMMERCE**
Structure	1	1	1	does have a structure
Plot size	4650.44	3529	–	square meters
Context	2.28	2	2	urban context
Operability	0.64	1	1	mostly operable
CLUSTERTYPE 3	**MEAN**	**MEDIAN**	**MODE**	**POLLUTING AGRICULTURE**
Structure	0	0	0	no structure
Plot size	4209	2451	–	square meters
Context	1	1	1	agricultural context
Operability	0.4	0	0	sometimes operable
CLUSTERTYPE 4	**MEAN**	**MEDIAN**	**MODE**	**INDUSTRIAL GIANTS**
Structure	1	1	1	does have a structure
Plot size	45586.42857	36281	–	square meters
Context	2.714285714	3	3	urban context
Operability	0.857142857	1	1	operable
CLUSTERTYPE 5	**MEAN**	**MEDIAN**	**MODE**	**PERI-URBAN PLAINS**
Structure	0	0	0	no structure
Plot size	45243.83333	44599	–	square meters
Context	1.5	2	2	urban/agricultural context
Operability	0.333333333	0	0	mostly inoperable

SITE TYPOLOGIES

SITE TYPOLOGY I - INDUSTRIAL GIANTS

Cluster 1 resembles the industrial giants. Within the industrial zones a lot of mega sized heavy industry is located. Processing of harmful material is mostly the cause of pollution. Most of these industrial sites are still in operation. Design strategies for this typology could encompass the buffering of the contaminated site from agricultural/urban land-use or redeveloping the sites into forests to create biomass or other green energy solutions.

8%
OF ALL SITES

15%
ABANDONED

85%
PRESENCE OF BUILDINGS OR STRUCTURES

2 TO 10HA
PLOT SIZE

SITE TYPOLOGY II - INDIVIDUAL INDUSTRY

The second type resembles small, individual industrial and commercial plots. These contaminated locations have a mean plot size of approximately 0.5 ha and are located in the urban areas, mainly towards the urban edges and into the industrial zones. Contamination is often the result of the harmful goods, spillage or mismanagement of waste and products. Most of these sites are still functioning.

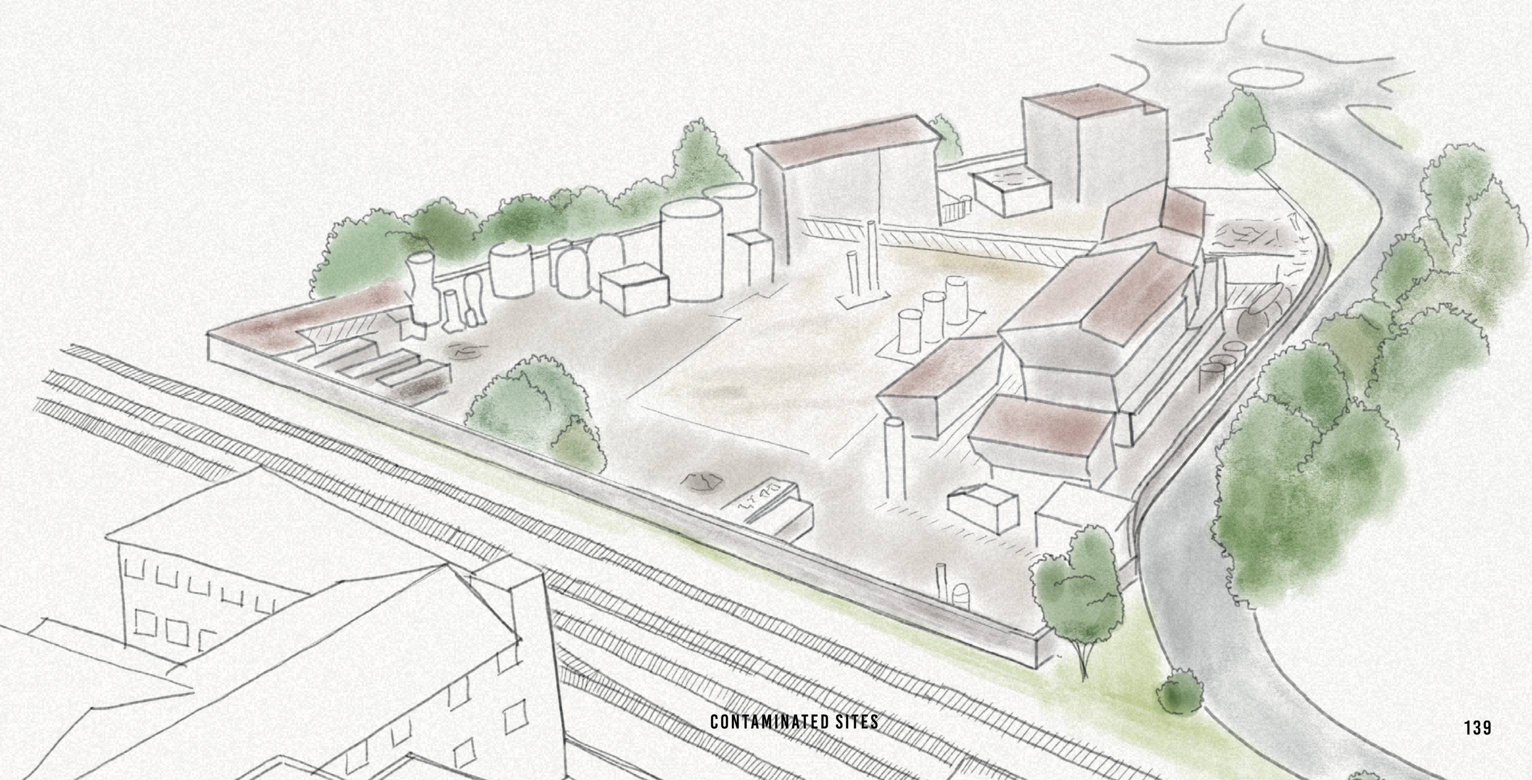
Design strategies for this typology could encompass the buffering of the contaminating industries from the urban land-use by dense vegetation, the implementation of flora within the industrial sites by means of landscaping, and the implementation of green energy production in combination with remediating grass species.

30%
OF ALL SITES

64%
ABANDONED

100%
PRESENCE OF BUILDINGS OR STRUCTURES

0.1 TO 1.5HA
PLOT SIZE



SITE TYPOLOGY III - URBAN INCIDENTS

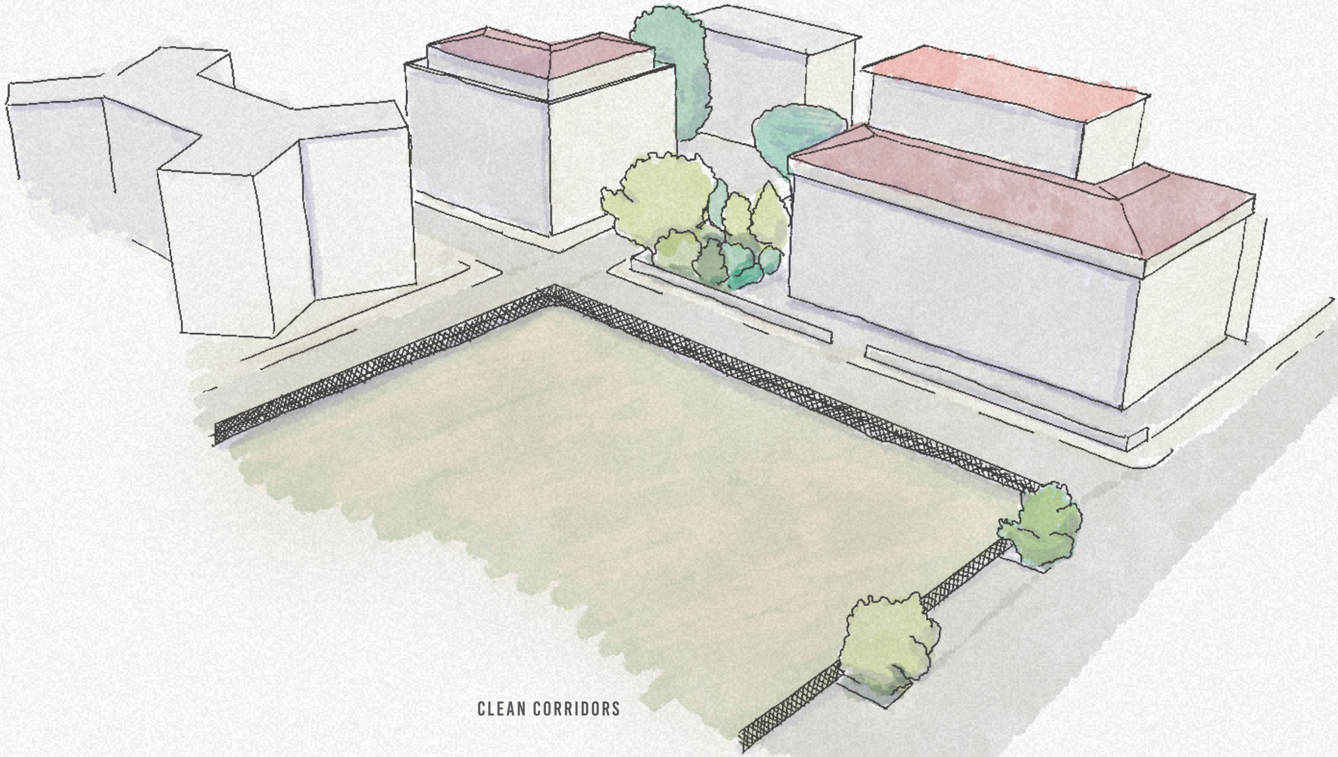
Cluster 3 resembles the urban incidents. Due to causes like spillage incidents or pipelines bursts very local soil contamination occurs. These locations are mostly small in size without major structure or buildings present. Most of the time, these sites are not in use, sometimes they may even be fenced off or gated to prevent interaction with the contamination. The urban incidents are mainly located towards the urban cores and have a lot of possibilities to be transformed into locations for social programs or parks, combining the urban program with phytoremediation practices.

36%
OF ALL SITES

50%
ABANDONED

0%
PRESENCE OF BUILDINGS OR STRUCTURES

0.1 TO 0.3HA
PLOT SIZE



SITE TYPOLOGY IV - PERI-URBAN PLAINS

Cluster 4 resembles the peri-urban plains. Often found at the edge of the urban cores, large contaminated plots can be found. Examples of this typology are the Silvio Piola Sports Park in Novara, or the former airport of Vercelli. These large areas are often contaminated due to former use of polluting materials, spillage, or as is the case in the sports park a pipeline burst. Areas within this typology typically do not have any structures, and are completely abandoned and gated to prevent human interaction with the contaminants.

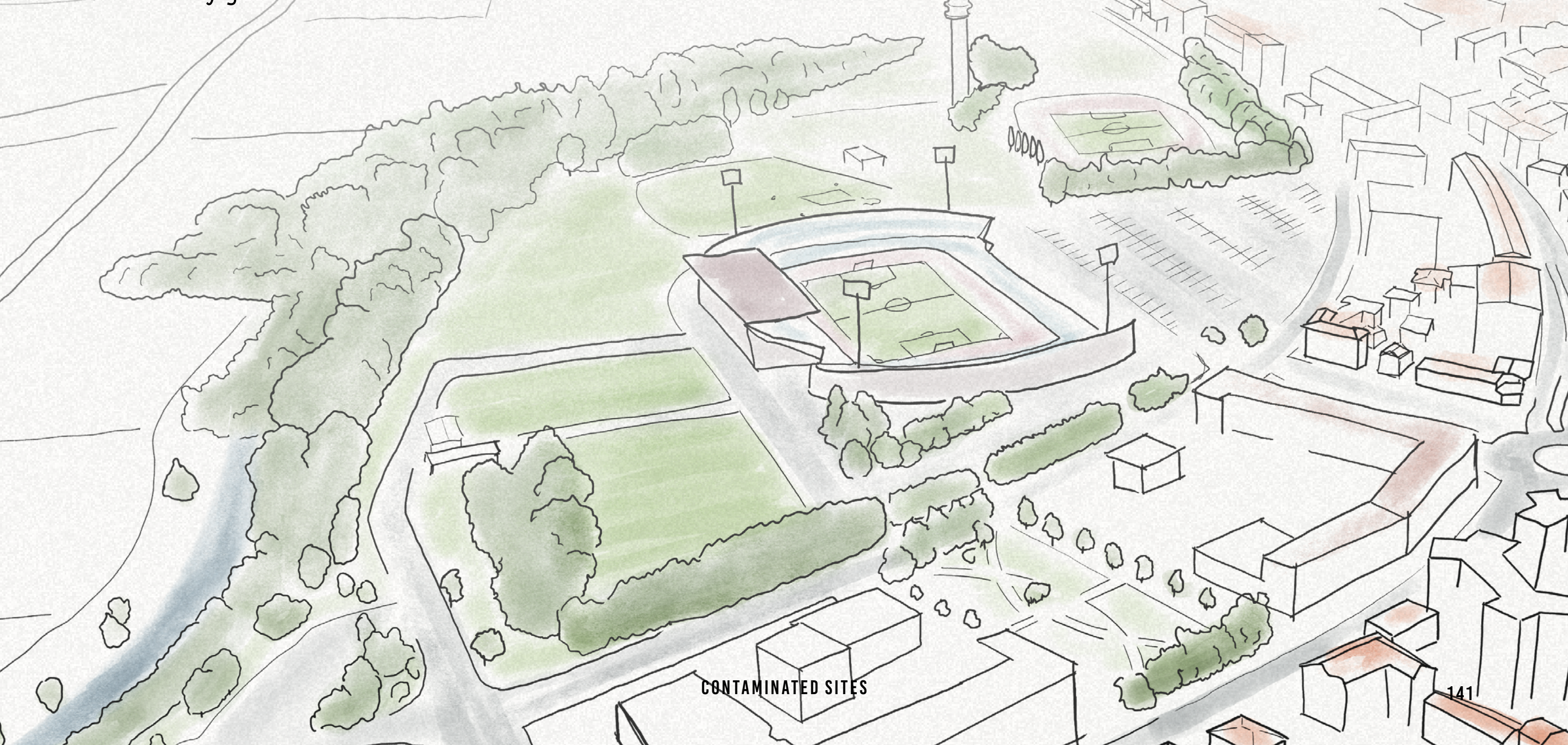
As these locations often form the border between urban areas and the agricultural landscape, these areas can possibly be redeveloped into large peri-urban parks connected to the landscape as well as the urban green structure, they can be used as a rural-urban gradient and house orchards or community gardens.

7%
OF ALL SITES

67%
ABANDONED

0%
PRESENCE OF BUILDINGS OR STRUCTURES

3 TO 6HA
PLOT SIZE



SITE TYPOLOGY V - CONTAMINATED AGRICULTURE

Cluster 5 resembles polluting agriculture. Within the agricultural landscape a lot of contaminated sites can be identified. These sites are generally medium to large scale and are located outside of the urban cores. The sites are polluted with pesticides, organic pollutants or heavy metals due to mismanagement or pollution agricultural practices. Operability of these sites are varying, but most are abandoned. The sites can have structures or buildings, but not necessarily.

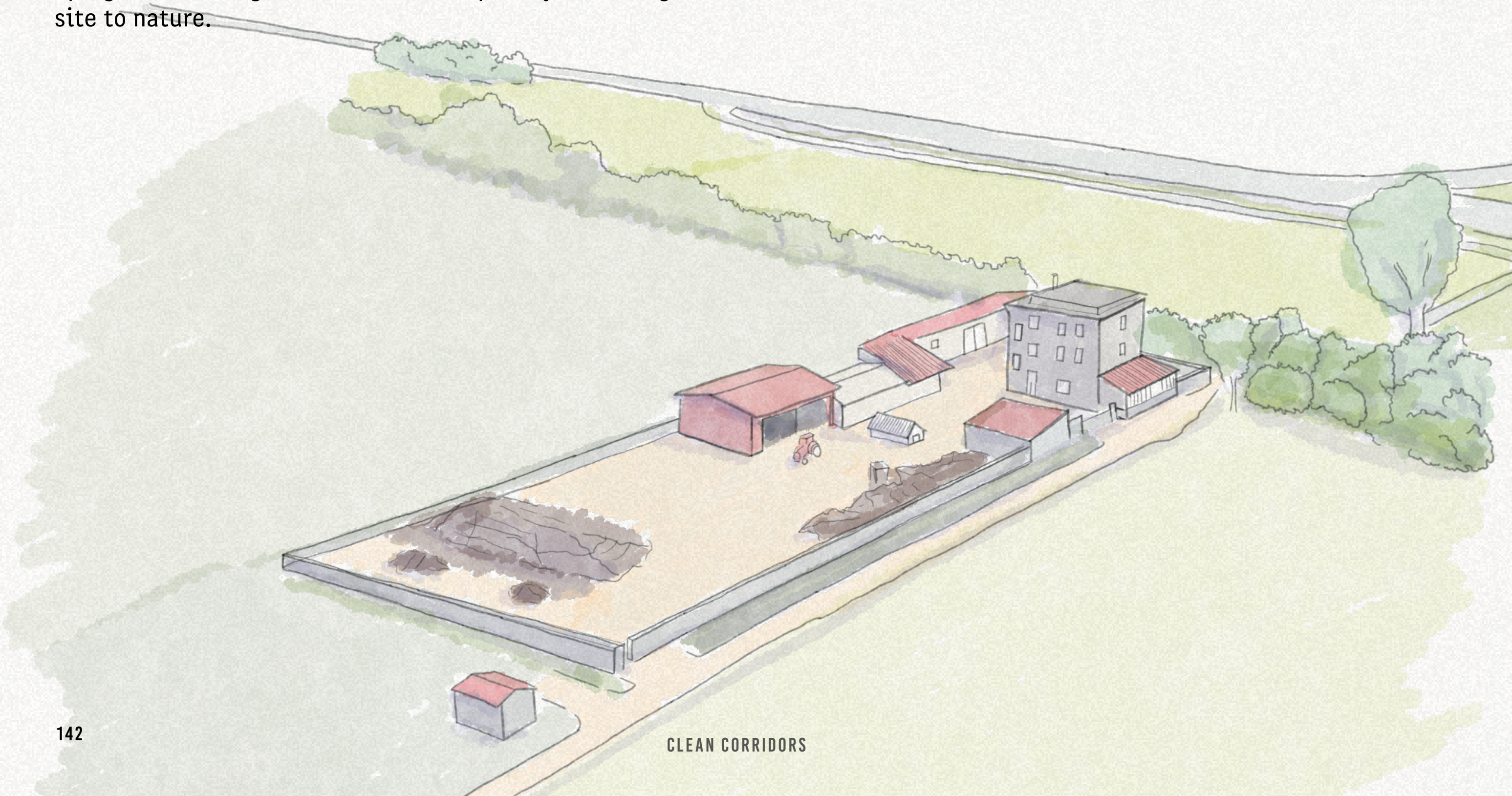
Design strategies for this typology could encompass the reintroduction of agriculture in a sustainable way by introducing tolerant crops together or in rotation with phytoremediation plant species, creating agritourism by redeveloping the existing structures or completely returning the site to nature.

18%
OF ALL SITES

60%
ABANDONED

15%
PRESENCE OF BUILDINGS OR STRUCTURES

0.2 TO 0.6HA
PLOT SIZE



DESIGN INTERVENTIONS

INTRODUCTION

To achieve the design strategies and goals that are established per site typology multiple micro-scale design interventions can be implemented. These design interventions are presented as a pattern language. Patterns can be introduced as adaptable principles applicable to a range of different contexts and settings. Alexander et al. (1977) introduced the concepts of design patterns. They serve as foundational guidelines for addressing specific design challenges within varying spatial environments. Each pattern provides information about the requirements for implementation, their unique value, and how and where these patterns can be implemented.

A pattern language is a design tool that addresses design solutions and brings them back to fundamental principles that can be applied across different contexts. The patterns are not fixed and aim for flexible implementation, being adapted to the specific circumstances of the context and situation in which it is applied. The patterns allow for quick exploration of possible solution directions.

Moreover, patterns serve as an important and useful communication tool. Well-defined patterns facilitate collaboration between stakeholders and designers. Through clear summaries and explanations, they make accessible design options that also allow non-designers to be incorporated within the design process by providing them with tools and guidance.

PATTERN TEMPLATE

The patterns contain varying objectives, aims, and requirements. The pattern template is designed to quickly and easily communicate these variables. The top of the card shows the pattern title, together with a quick visualization. Left of the image, the land use where this intervention would fit in is depicted. Some functionalities are specifically aimed for agricultural use or urban environments.

Next to the land use, a column for the scale of the intervention is depicted. Interventions are classified into three scales, with the largest being on a landscape scale covering multiple plots and often multiple hectares. The medium scale is the size of an entire plot, and the smallest scale is merely a part of a plot. Large-scale interventions often extend far over the site boundaries, while multiple small-scale interventions could be applied within one contaminated site. Combining multiple interventions, on multiple scales or at the same location can also be possible.

Intervention patterns are purely spatial and are not site and contaminant specific, the application and selection of phytoremediating species follows based on the data and information of the site it is applied on. However, certain interventions can have spatial requirements for the plant that are used in combination with them. An example of this is sustainable parking spaces, where permeable pavement is used in combination with phytoremediation grasses and herbs to remediate the soil. This pattern requires the use of grasses and cannot be combined with large shrubs or trees. The plant habits required by the intervention are shown in the column on the right of the pattern template.

Underneath the general intervention description, the phytostrategy is shown. This refers to the aims and goals of the design intervention. The phytostrategies include accumulation & extraction, tolerance, stabilization, and physical buffering. Accumulation and extraction is the term that most resembles the regular view of phytoremediation, and aims at the uptake, and/or storage, and/or degradation of contaminants by the plants. Stabilization prevents the spread of the contaminants to neighboring areas, while physical buffers prevent people from getting in contact with the contaminated area. Interventions aimed at tolerance do not actively remediate the area but can be used in combination with other interventions to give new functions and more value to the remediated site.

REQUIRED SCALE/SPACE

- Landscape (>1ha)
- Site (<1ha)
- Micro (<100 m²)

APPROPRIATE LULC

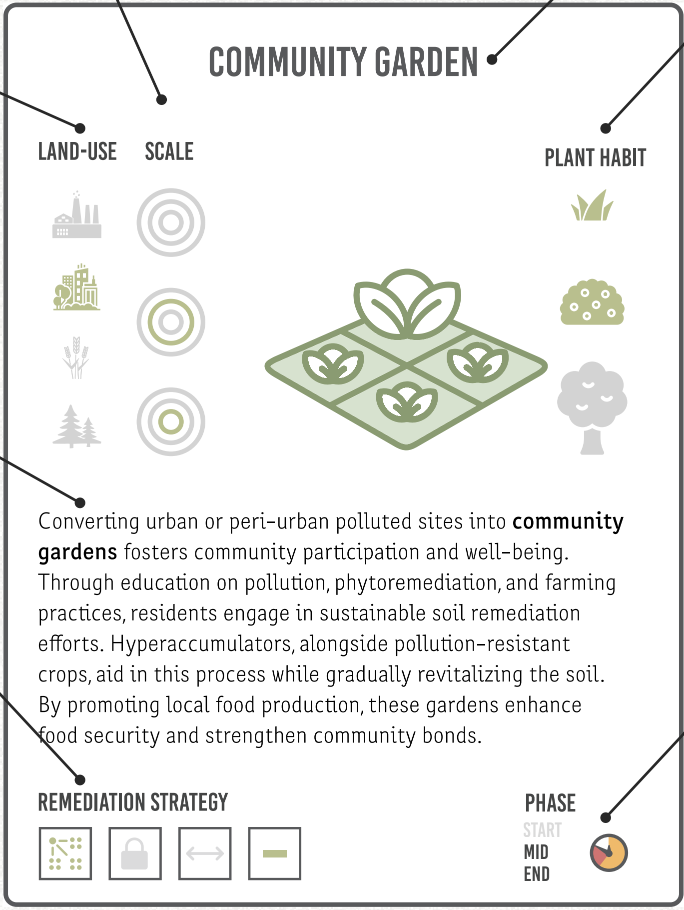
- Industrial
- Urban
- Agricultural
- Natural

PATTERN TITLE

VEGETATION REQUIREMENT

Requirements on growth habit or vegetation type to make it fit the spatial intervention.

- Herbaceous
- Shrubs
- Trees



PATTERN DESCRIPTION

Definition and primary properties of the pattern in max. 250 words.

REMEDIATION STRATEGY

- Remediation
- Stabilization
- Buffering
- Tolerance

APPROPRIATE PHASE

Requirements on growth habit or vegetation type to make it fit the spatial intervention.

- Herbaceous
- Shrubs
- Trees

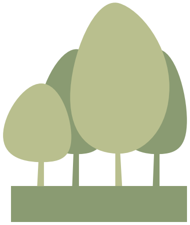
Lastly, the phase of implementation is shown in the bottom-right corner of the template. As phytoremediation is a time-consuming process, which often takes multiple years or even decades to complete, phasing is an important element in designing phytosystems. During the remediation, contaminant concentrations decrease, allowing more or different functions to be introduced to the area. Because the phasing is site and contaminant-specific, the phasing is simplified into three parts: start-phase, mid-phase, and end-phase. Design interventions can be rotated and alternated according to the phase that the phytosystem is in. The following pages give an overview of the pattern language.

PATTERN LANGUAGE OVERVIEW

POCKET PARK

LAND-USE SCALE

PLANT HABIT



Transforming pollution sites into **pocket parks and urban green** spaces offers a sustainable solution for remediation and community revitalization that enhance urban aesthetics, biodiversity, and local green structures. Converting pollution sites into pocket parks promotes recreational activities, social interaction, and mental health benefits for residents. Pocket parks and urban green transformation turns once-neglected spaces into valuable assets for urban living.

REMEDIATION STRATEGY

PHASE
START
MID
END

INDUSTRIAL BUFFER

LAND-USE SCALE

PLANT HABIT

Buffer zones around active industrial sites mitigate pollution emissions, prevent runoff, and deter future pollution spread. This strategy establishes a separation between urban well-being and industrial pollutants, safeguarding community health. By containing pollution and restricting industrial encroachment into urban areas, buffer zones foster environmental protection and urban sustainability.

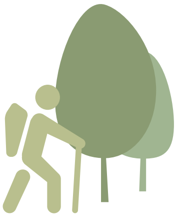
REMEDIATION STRATEGY

PHASE
START
MID
END

LEISURE PARK

LAND-USE SCALE

PLANT HABIT



Large-scale, severely polluted areas offer potential for transformation into **leisure and recreational parks**, integrating phytoremediation in phased approaches. Incorporating amenities like walking and cycle paths, bird watching spots, and skateparks revitalizes urban and peri-urban landscapes. This strategy, complemented by existing green structures, enhances environmental sustainability, biodiversity and community well-being.

REMEDIATION STRATEGY

PHASE
START
MID
END

COMMUNITY GARDEN

LAND-USE SCALE

PLANT HABIT

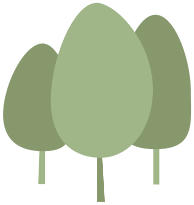
Converting urban or peri-urban polluted sites into **community gardens** fosters community participation and well-being. Through education on pollution, phytoremediation, and farming practices, residents engage in sustainable soil remediation efforts. Hyperaccumulators, alongside pollution-resistant crops, aid in this process while gradually revitalizing the soil. By promoting local food production, these gardens enhance food security and strengthen community bonds.

REMEDIATION STRATEGY

PHASE
START
MID
END

PROTECTED NATURE

LAND-USE SCALE PLANT HABIT



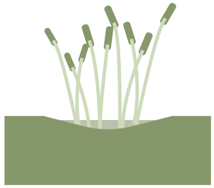
In remote and heavily contaminated sites unsuitable for socio-economic solutions, **transformation into natural habitats** through phytoremediation offers an ecological remedy. Specifically chosen phytoremediating species that require no harvest, restore ecological balance and provide habitat for diverse wildlife. Though less beneficial for human uses due to lacking infrastructure, this approach strengthens ecological resilience and fosters biodiversity.

REMEDIATION STRATEGY

PHASE
START
MID
END

CONSTRUCTED WETLANDS

LAND-USE SCALE PLANT HABIT



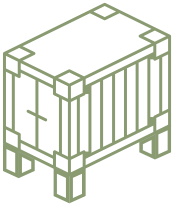
Constructed wetlands mimic the natural processes of wetlands, utilizing a combination of vegetation, soil, and microbial communities to treat polluted water. As water flows through the wetland, pollutants such as heavy metals, nutrients, and organic compounds are absorbed, transformed, or degraded by plants and microorganisms. These wetlands are a long term solution and can only be implemented in sites which allow for remediation over longer periods of time.

REMEDIATION STRATEGY

PHASE
START
MID
END

TEMPORAL ELEVATED PROGRAM

LAND-USE SCALE PLANT HABIT



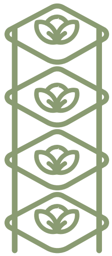
Temporary elevated program combined with phytoremediation offers a sustainable approach to site remediation. Utilizing containers for the program enhances convenience in transformation and transport, facilitating easy adaptation to varying site conditions and allows for placemaking. Elevating the program maximizes the planting area for hyperaccumulators, optimizing pollutant absorption in compact urban spaces, where pollution sites are of limited size. Mulitple units can be combined for application in larger plots.

REMEDIATION STRATEGY

PHASE
START
MID
END

VERTICAL FARMING

LAND-USE SCALE PLANT HABIT



Repurposing inactive polluted warehouses and industrial buildings into **urban/vertical farms** presents a dual solution for environmental remediation and sustainable food production. By utilizing the ground floor for phytoremediation and hyperaccumulators, pollutants can be absorbed and detoxified, improving soil quality. Meanwhile, multiple floors can host sustainable, local food production, maximizing land use efficiency.

REMEDIATION STRATEGY

PHASE
START
MID
END

SUSTAINABLE PARKING LOT

LAND-USE SCALE PLANT HABIT

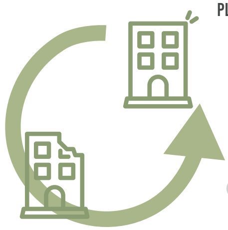
Sustainable parking spaces employing semi-open pavement and hyperaccumulators allow rainwater to penetrate the ground, reducing runoff and facilitating natural filtration processes. Hyperaccumulators planted in these spaces absorb and detoxify pollutants from the soil, gradually remediating contamination. This approach is especially useful in urban and industrial areas which are bound to car accessibility.

REMEDIATION STRATEGY

PHASE
START
MID
END

BUILDING TRANSFORMATION

LAND-USE SCALE PLANT HABIT



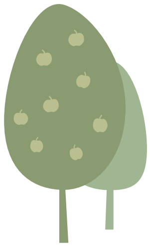
Former **industrial** sites with abandoned structures hold potential for **conversion** into residential spaces, offices, retail areas, and ateliers, among other functions. Shifting the focus away from heavy infrastructure and transportation allows for more pavement conversion to open soil, facilitating phytoremediation. Incorporating temporary functions can gradually transition the area into a green space, preparing it for future development.

REMEDIATION STRATEGY

PHASE
START
MID
END

ORCHARDS

LAND-USE SCALE PLANT HABIT



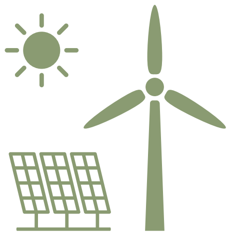
Transforming larger polluted peri-urban and urban plots into **orchards** offers a multifaceted solution by combining phytoremediation with diverse tree species. This approach revitalizes connections between food production and the urban environment. Orchards not only mitigate pollution through phytoremediation but also serve as educational tools, teaching communities about sustainable food production and the remediation of polluted landscapes.

REMEDIATION STRATEGY

PHASE
START
MID
END

GREEN ENERGY PRODUCTION

LAND-USE SCALE



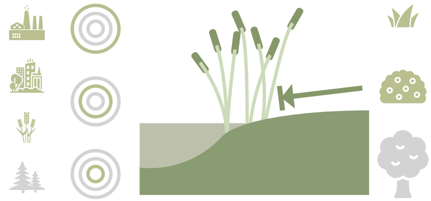
In areas lacking social opportunities, transformation can prioritize **green energy production** by integrating phytoremediating plants with photovoltaic panels or wind turbines. Combining greenery with PV panels enhances energy production efficiency. This solution, devoid of direct social benefits, targets locations where alternative design options are undesirable or unfeasible.

REMEDIATION STRATEGY

PHASE
START
MID
END

STORMWATER FILTERS

LAND-USE SCALE PLANT HABIT



Stormwater filters can capturing and treating runoff laden with pollutants. These filters, typically installed in urban areas, can be strategically placed in locations prone to runoff from paved surfaces, industrial areas, and agricultural lands, mostly along paved infrastructure. Stormwater filters help prevent further soil contamination and water pollution.

REMEDIATION STRATEGY

PHASE
START
MID
END

BIO-ENERGY PRODUCTION

LAND-USE SCALE PLANT HABIT

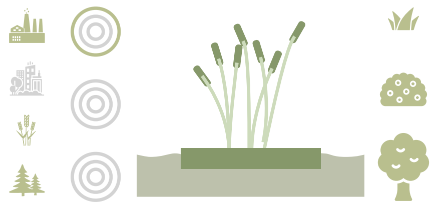
Hyperaccumulators yield significant biomass quickly, offering an economic opportunity for **biofuel and bioenergy production** in polluted landscapes. As this transformation option requires a lot of infrastructure and processing, this solution is most feasible in larger plots outside urban areas due to space constraints and the absence of other social values.

REMEDIATION STRATEGY

PHASE
START
MID
END

FLOATING WETLANDS

LAND-USE SCALE PLANT HABIT



Floating wetlands consist of buoyant platforms supporting wetland vegetation, which efficiently absorb and detoxify contaminants from water bodies. By harnessing the natural filtration capabilities of plants like reeds, cattails, and water hyacinths, floating wetlands offer a sustainable solution for water purification while improving biodiversity and habitat quality.

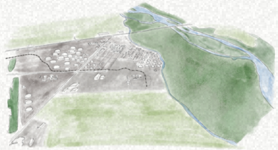
REMEDIATION STRATEGY

PHASE
START
MID
END

PHASING & TYPOLOGIES

START-PHASE

INDUSTRIAL GIANTS



BIO-ENERGY PRODUCTION

LAND-USE SCALE PLANT HABIT

Hyperaccumulators yield significant biomass quickly, offering an economic opportunity for **biofuel and bioenergy production** in polluted landscapes. As this transformation option requires a lot of infrastructure and processing, this solution is most feasible in larger plots outside urban areas due to space constraints and the absence of other social values.

REMEDIATION STRATEGY

PHASE START MID END

INDUSTRIAL BUFFER

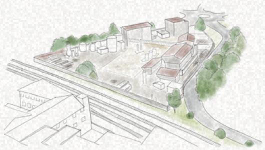
LAND-USE SCALE PLANT HABIT

Buffer zones around active industrial sites mitigate pollution emissions, prevent runoff, and deter future pollution spread. This strategy establishes a separation between urban well-being and industrial pollutants, safeguarding community health. By containing pollution and restricting industrial encroachment into urban areas, buffer zones foster environmental protection and urban sustainability.

REMEDIATION STRATEGY

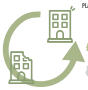
PHASE START MID END

INDIVIDUAL INDUSTRIES



BUILDING TRANSFORMATION

LAND-USE SCALE PLANT HABIT



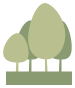
Former **industrial** sites with abandoned structures hold potential for **conversion** into residential spaces, offices, retail areas, and ateliers, among other functions. Shifting the focus away from heavy infrastructure and transportation allows for more pavement conversion to open soil, facilitating phytoremediation. Incorporating temporary functions can gradually transition the area into a green space, preparing it for future development.

REMEDIATION STRATEGY

PHASE START MID END

POCKET PARK

LAND-USE SCALE PLANT HABIT



Transforming pollution sites into **pocket parks and urban green** spaces offers a sustainable solution for remediation and community revitalization that enhance urban aesthetics, biodiversity, and local green structures. Converting pollution sites into pocket parks promotes recreational activities, social interaction, and mental health benefits for residents. Pocket parks and urban green transformation turns once-neglected spaces into valuable assets for urban living.

REMEDIATION STRATEGY

PHASE START MID END

VERTICAL FARMING

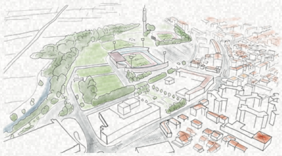
LAND-USE SCALE PLANT HABIT

Repurposing inactive polluted warehouses and industrial buildings into **urban/vertical farms** presents a dual solution for environmental remediation and sustainable food production. By utilizing the ground floor for phytoremediation and hyperaccumulators, pollutants can be absorbed and detoxified, improving soil quality. Meanwhile, multiple floors can host sustainable, local food production, maximizing land use efficiency.

REMEDIATION STRATEGY

PHASE START MID END

PERI-URBAN PLAINS



SUSTAINABLE PARKING LOT

LAND-USE SCALE PLANT HABIT

Sustainable parking spaces employing semi-open pavement and hyperaccumulators allow rainwater to penetrate the ground, reducing runoff and facilitating natural filtration processes. Hyperaccumulators planted in these spaces absorb and detoxify pollutants from the soil, gradually remediating contamination. This approach is especially useful in urban and industrial areas which are bound to car accessibility.

REMEDIATION STRATEGY

PHASE START MID END

LEISURE PARK

LAND-USE SCALE PLANT HABIT

Large-scale, severely polluted areas offer potential for transformation into l**eisure and recreational parks**, integrating phytoremediation in phased approaches. Incorporating amenities like walking and cycle paths, bird watching spots, and skateparks revitalizes urban and peri-urban landscapes. This strategy, complemented by existing green structures, enhances environmental sustainability, biodiversity and community well-being.

REMEDIATION STRATEGY

PHASE START MID END

CONSTRUCTED WETLANDS

LAND-USE SCALE PLANT HABIT

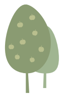
Constructed wetlands mimic the natural processes of wetlands, utilizing a combination of vegetation, soil, and microbial communities to treat polluted water. As water flows through the wetland, pollutants such as heavy metals, nutrients, and organic compounds are absorbed, transformed, or degraded by plants and microorganisms. These wetlands are a long term solution and can only be implemented in sites which allow for remediation over longer periods of time.

REMEDIATION STRATEGY

PHASE START MID END

ORCHARDS

LAND-USE SCALE PLANT HABIT

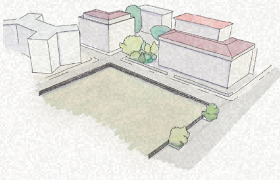


Transforming larger polluted peri-urban and urban plots into **orchards** offers a multifaceted solution by combining phytoremediation with diverse tree species. This approach revitalizes connections between food production and the urban environment. Orchards not only mitigate pollution through phytoremediation but also serve as educational tools, teaching communities about sustainable food production and the remediation of polluted landscapes.

REMEDIATION STRATEGY

PHASE START MID END

URBAN INCIDENTS



STORMWATER FILTERS

LAND-USE SCALE PLANT HABIT

Stormwater filters can capturing and treating runoff laden with pollutants. These filters, typically installed in urban areas, can be strategically placed in locations prone to runoff from paved surfaces, industrial areas, and agricultural lands, mostly along paved infrastructure. Stormwater filters help prevent further soil contamination and water pollution.

REMEDIATION STRATEGY

PHASE START MID END

TEMPORAL ELEVATED PROGRAM

LAND-USE SCALE PLANT HABIT

Temporary elevated program combined with phytoremediation offers a sustainable approach to site remediation. Utilizing containers for the program enhances convenience in transformation and transport, facilitating easy adaptation to varying site conditions and allows for placemaking. Elevating the program maximizes the planting area for hyperaccumulators, optimizing pollutant absorption in compact urban spaces, where pollution sites are of limited size. Mulitple units can be combined for application in larger plots.

REMEDIATION STRATEGY

PHASE START MID END

COMMUNITY GARDEN

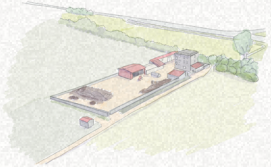
LAND-USE SCALE PLANT HABIT

Converting urban or peri-urban polluted sites into **community gardens** fosters community participation and well-being. Through education on pollution, phytoremediation, and farming practices, residents engage in sustainable soil remediation efforts. Hyperaccumulators, alongside pollution-resistant crops, aid in this process while gradually revitalizing the soil. By promoting local food production, these gardens enhance food security and strengthen community bonds.

REMEDIATION STRATEGY

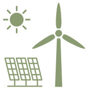
PHASE START MID END

POLLUTED AGRICULTURE



GREEN ENERGY PRODUCTION

LAND-USE SCALE



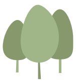
In areas lacking social opportunities, transformation can prioritize **green energy production** by integrating phytoremediating plants with photovoltaic panels or wind turbines. Combining greenery with PV panels enhances energy production efficiency. This solution, devoid of direct social benefits, targets locations where alternative design options are undesirable or unfeasible.

REMEDIATION STRATEGY

PHASE START MID END

PROTECTED NATURE

LAND-USE SCALE PLANT HABIT



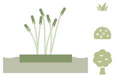
In remote and heavily contaminated sites unsuitable for socio-economic solutions, **transformation into natural habitats** through phytoremediation offers an ecological remedy. Specifically chosen phytoremediating species that require no harvest, restore ecological balance and provide habitat for diverse wildlife. Though less beneficial for human uses due to lacking infrastructure, this approach strengthens ecological resilience and fosters biodiversity.

REMEDIATION STRATEGY

PHASE START MID END

FLOATING WETLANDS

LAND-USE SCALE PLANT HABIT



Floating wetlands consist of buoyant platforms supporting wetland vegetation, which efficiently absorb and detoxify contaminants from water bodies. By harnessing the natural filtration capabilities of plants like reeds, cattails, and water hyacinths, floating wetlands offer a sustainable solution for water purification while improving biodiversity and habitat quality.

REMEDIATION STRATEGY

PHASE START MID END

TIME/PHASE →

MID-PHASE	END-PHASE

CONCLUSION

Mapping the contaminated sites in the region showed a great variety of locations. By clustering and classifying these sites using a k-means clustering method, the recurring patterns became visible, resulting in five generic types. These types served as the foundation for designing and creating design solutions in the form of a pattern language.

The presented pattern language present potential design solutions for redesigning contaminated sites. As the patterns are very generalized, they have to be adapted and fitted to the actual sites during implementation. This pattern language is open-ended and can be expanded freely. The following chapter will give to exemplary showcases of the implementation of these patterns, as well as the selection of appropriate vegetation to fit the combination of selected patterns and site properties.

06

IMPLEMENTATION & SHOWCASE

REMEDIATION SITE I - INDUSTRIAL GIANT

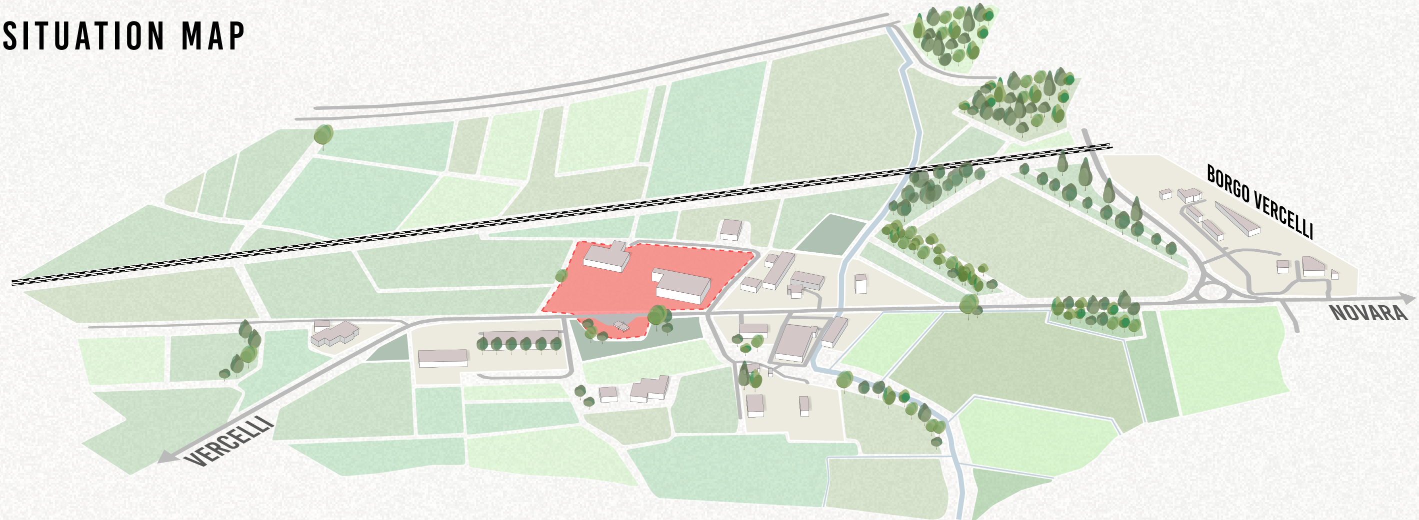
TRACTOR MANUFACTURER BORGO VERCELLI

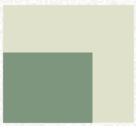
Situated just 3 kilometers from the city of Vercelli, lies the first showcase location for implementing the design strategies at the local scale. This site of approximately 20,000 square meters is identified by the Piedmont Region as a contaminated site in need of remediation. It is home to a manufacturer of agricultural machinery, which due to poor management practices regarding storage and waste treatment, has polluted the site's soil with various contaminants. Specialized in machinery tailored to minimize impact on the agricultural soil and crops, specifically for the local rice paddies, the facility includes areas for assemblage, industrial cleaning, painting, and storage. Despite the considerably sized warehouses, many products and elements are stored outdoors, contributing to soil contamination of heavy metals, VOCs, and petrol.

Recognizing the site's economic importance and its impact in supporting sustainable practices within local agriculture, the design goals aim to preserve the current functionalities of the site. Proposed interventions within the site perimeters will have to fit the current program, whilst the main focus of the design would be to lock the contaminants in place and prevent further dispersal of the pollution to the surrounding environment.

The site's direct surroundings include several smaller commercial establishments like furniture and curtains stores, a bowling alley, and a petrol station. This is all situated within a primarily agricultural landscape, being mostly rice paddies. Given the high irrigation needs of rice cultivation, there are numerous irrigation channels and high groundwater tables. Looking further north, we find the small town of Borgo Vercelli at approximately 500 meters of our intervention location. This town's land use is primarily residential, as the commercial and industrial activities concentrate around the larger city of Vercelli.

SITUATION MAP

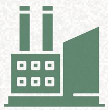




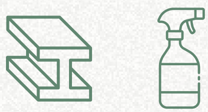
AREA - 20.000 M^2

RUN-OFF IN WATER

FUNCTIONING SITE



INDUSTRIAL CONTEXT



HEAVY METAL & TCE/PCE POLLUTION

POSITION WITHIN CORRIDOR

LOCATION CHARACTERISTICS

SOIL TYPE	Eutric Fluvisol
SOIL SALINITY	Non-saline soil
SOIL PH	±6.4
ORGANIC CARBON DENSITY	25 kg/m³
CLIMATE	Humid subtropical climate
MIN. TEMPERATURE	-5°C

GROUND WATER DEPTH	High groundwater table
LIST OF POTENTIAL CONTAMINANTS	• Cadmium (Cd) • Mercury (Hg) • Petroleum • Hydrocarbons • Trichlorethylene • Pentachlorethylene

CURRENT USE & DESIGN GOALS

The manufacturing facility at this site produces a diverse array of agricultural machinery, ranging from tractor attachments to more futuristic, self-operating equipment. These products are designed, tested, and assembled at the site itself. These activities take place within the two main buildings, being one large warehouse and office complex, and a manufacturing and cleaning facility. Surrounding these structures is a substantial (unpaved) area, designated for the storage of finished and unfinished machinery components, as well as employee and visitor parking.

Opposite the site, across the main street, lies an unmanned petrol station. The petrol station is characterized by a large and empty paved surface exhibiting evidence of petroleum spillage. Therefore, I want to include this area in the redesign. The site features delivery package lockers, indicating a demand for urban amenities within the area. However, the overall settlement lacks quality public spaces and misses areas for relaxation or work breaks.

When comparing the site's characteristics to the different site typologies established in the previous chapter, this site would be characterized as an 'industrial giant' site type. Following the strategies and guidelines derived from the typology would lead to the following objectives:

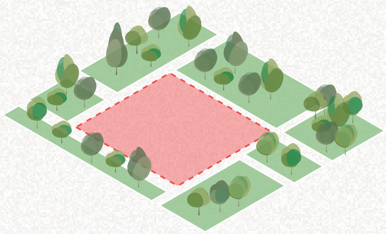
1. **Buffering the industry and its pollution from the environment.** . As the site's current function is to be maintained, remediation interventions primarily focus on the immediate surroundings of the site, seeking to lock existing contaminants in place and mitigate their spread to surrounding agricultural and urban landscapes. Additionally, the interventions aim to visually and physically segregate the industrial and urban territories.

2. **Promoting sustainability.** The interventions aim to support a more sustainable future for industrial activities. They should support the use or production of sustainable materials that are used in the local industry, contribute to a more renewable energy mix used in manufacturing, or decrease the energy use of the site.

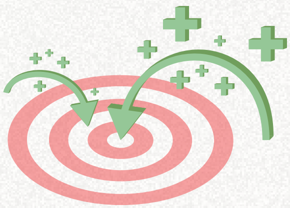
3. **Creating local benefits.**

Redesign efforts prioritize the utilization of resources and amenities to cater to local needs, ensuring that energy generated is consumed within the community, and recreational spaces cater primarily to local residents.

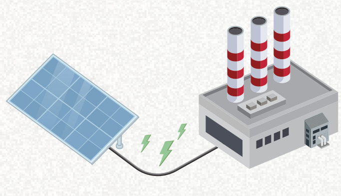
DESIGN GUIDELINES



BUFFERING THE INDUSTRIAL (POLLUTION)



LOCAL INTERVENTION EQUALS LOCAL BENEFITS



GREENING THE INDUSTRIAL PRODUCITON

SITE IMAGES


LAVAGGI INDUSTRIALI
5 SPAZZOLE
AUTOMEZZI PESANTI
CISTERNE-SILOS-CONTAINERS
OFFICINA AGRICOLA
SABATINO R. & Figli
LAVAGGIO CAMION
LAVAGGIO


TAMOIL
Diesel
SenzaPb
GPL

TRACTOR MANUFACTURER BORGO VERCELLI

The remediation site and its direct surroundings are redesigned using a variety of design interventions that fit the spatial configuration of the location. These design interventions require some tailoring to the specific local climate and soil conditions to be useful, including the selection of fitting plant species that can survive the contamination and the soil conditions described in the table on the previous page.

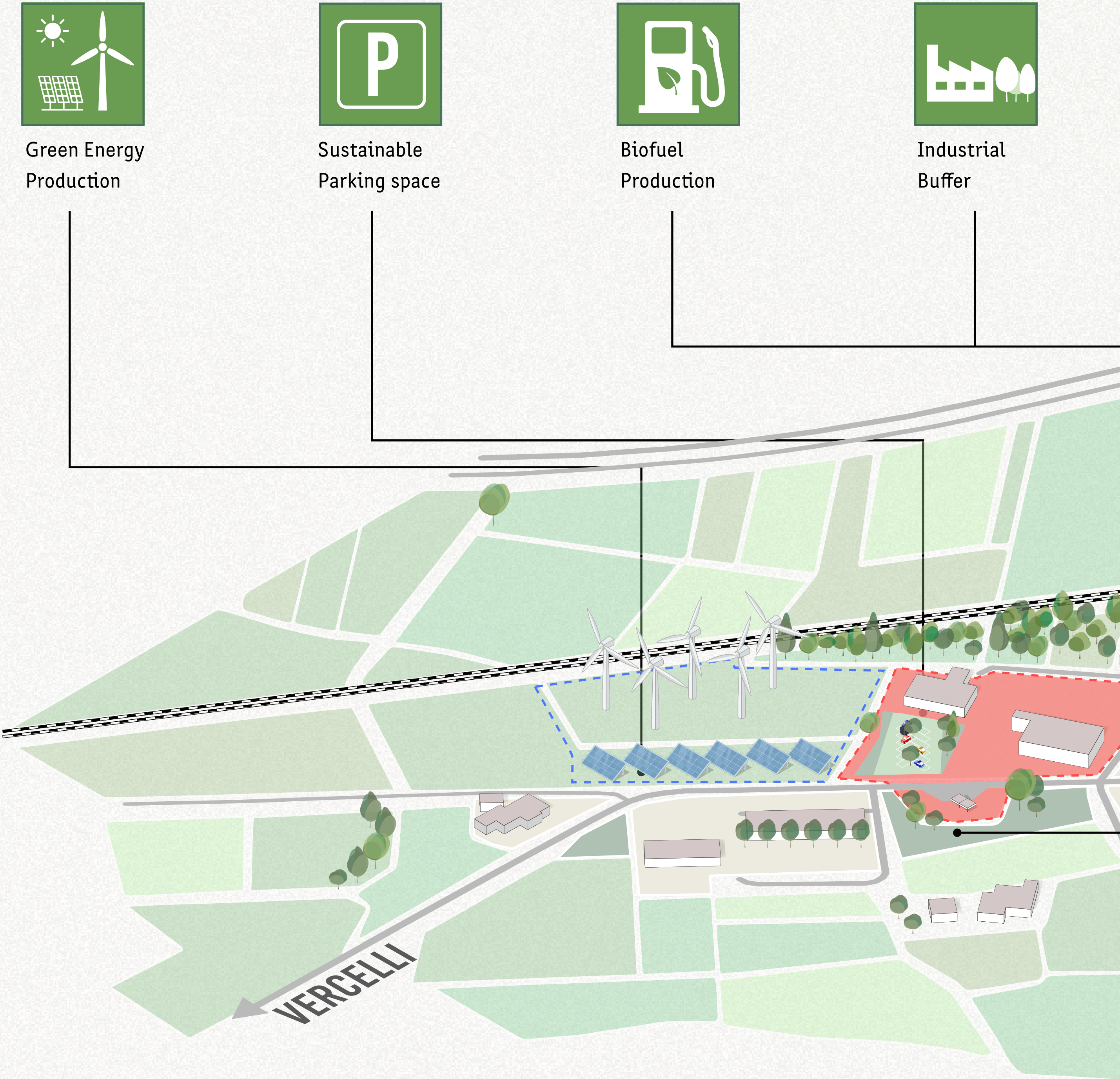
The barren grasslands directly southwest of the design location offer an opportunity for the introduction of green energy production to the area. As the site is likely to be contaminated by run-off from the polluted site, this area presents viable space for the combination of renewable energy sources with remediating plant species. Given the extremely low wind speeds in the Po-valley [cit], wind turbines are not feasible. Instead, agrivoltaics are introduced to the site. These overhead PV panels cover grassland or crops and protect them from rain, hail, and too much radiation or heat, while the PV panels take advantage of the cooling effect of evaporation from the plants underneath.

These agrivoltaics can be combined with different spatial functions, depending on the contamination level, allowing phasing of this design intervention. Initially, the area may be too contaminated and unsuitable for crop farming or husbandry, requiring time for phytoremediation to ameliorate the soil conditions to allow for agricultural activities. During this phase herbaceous (hyper)accumulators, such as Festuca arundinacea (Tall Fescue), Loliom Perenne (Perennial Ryegrass), and Rumex acetosa (Rumex), are used to remediate respectively petrol, industrial solvents including PCE/TCE and heavy metals such as cadmium and zinc. After this initial phase, which can take several years depending on the contaminant concentration, the site allows for husbandry and the introduction of contaminant-tolerant grass en herb species, including different types of Thlaspi spp. (Pennycress), Trifolium repens (White Clover) to further accumulate the contaminants and serve as animal feed. Subsequently, as the remediation progresses, the area becomes suitable for reintroducing crop farming of pollution excluders, this could be spinach, radish, several potato families, or Jerusalem artichokes.

The north and east of the site currently host some small forest patches. The individual patches are interconnected and integrated into the regional green corridor. By planting fast-growing accumulating tree species like Betula Pendula (Silver Birch), Salix Nigra (Black Willow), and Populus Nigra (Black Poplar) a diverse range of contaminants are addressed while quickly producing biomass for economic purposes. Notably, the biomass harvested from these trees can be used as a renewable energy source to be used in local combined cycle power plants or transformed into biofuel to be distributed via the local power plant. Apart from addressing the pollution and creating economic opportunities, this intervention functions as a visual and physical buffer between the industries of Borgo Vercelli, the agricultural landscape, and urban residence, minimizing pollutant transfer and enhancing living conditions.

Within the perimeters of the remediation site itself, substantial barren surfaces offer opportunities for soil remediation and functional enhancement. By creating designated parking and storage areas with semi-open and permeable pavement, grasses, and herbaceous (hyper)accumulators such as Cynodon dactylon (Bermuda grass) and Lolium perenne.

The following pages give an overview of a possible redesign of the site, using the patterns from the pattern language with appropriate and fitting phytoremediating vegetation.



DESIGN INTERVENTIONS


Connecting Green
Run-Off Prevention
Recreational (Pocket) Park
BORGO VERCELLI
NOVARA

ACCUMULATOR PLANTS OVERVIEW

BETULA PENDULA - SILVER BIRCH

- Deciduous tree (15-25m), fast growing
- Hyperaccumulator of TCE/PCE & heavy metals
- Phytostabilization, -extraction & accumulation

CHRYSANTHEMUM - CHRYSANTS

- Perrenial herbaceous flowers
- Accumulator of TCE/PCE & Petroleum
- Phytoextraction

GEBERA JAMESONII - GERBERA DAISY

- Perrenial herbaceous flowers
- Hyperaccumulator of TCE/PCE & Petroleum
- Phytoextraction
-

SALIX NIGRA - BLACK WILLOW

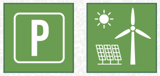
- Medium sized deciduous tree
- Accumulator of TCE/PCE, petroleum and heavy metals
- Phyto- & rhizodegradation, phytoextraction

POPULUS NIGRA - BLACK POPLAR

- Deciduous tree (25-30m)
- Accumulator of heavy metals & hydrocarbons
- Phytoextraction & -accumulation

CYNODON DACTYLON- BERMUDA GRASS

- Grass
- Accumulator of heavy metals & hydrocarbons
- Phytoextraction & -accumulation



LOLIUM PERENNE - PERENNIAL RYEGRASS

- Herbaceous grass (10-90cm)
- Accumulator of pentachlorophenol, Cd & Hg
- Fast growing, high yields
- Used for animal fodder or biomass
- Phytoextraction & rhiv vzoextraction

PHRAGMITES AUSTRALIS - COMMON REED

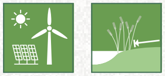
- Herbaceous helophyte (2-4m)
- Accumulator of bromoform, chlorobenzene, chloroform, dichloroethane, PCE, TCE
- Fast growing, high yields
- Used for tatch housing, fodder, food
- Phytoextraction & -accumulation

FESTUCA ARUNDINACEA - TALL FESCUE

- Perennial grass (<165cm)
- Hyperaccumulator of arsenic, copper, lead & zinc
- Phytostabilization, -extraction, -degradation & rhizodegradation

RUMEX ACETOSA - SORREL

- Perrenial herbacious plant (60cm), deep roots
- Accumulator of zinc & lead
- Phytoextraction
- Used in soups, sauces and curries



THLASPI VAR. - PENNYCRESS

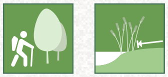
- Annual herbacious flower (<60cm)
- Hyperaccumulator of aluminium, chromium, cobalt, copper, lead, nickel, cadmium & zinc
- Phytoextraction & -stabilization

TRIFOLIUM REPENS - WHITE CLOVER

- Herbaceous perennial plant (5-10cm)
- Accumulator of diesel, petrol, PCB & other hydrocarbons
- Rhizodegradation

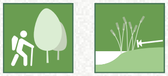
SALIX VIMINALIS - BASKET WILLOW

- Multi-stemmed shrub (3-6m)
- Accumulator of cadmium, chromium, lead, mercury, petroleum hydrocarbons, organic solvents, TCE, selenium and zinc
- Phytoextraction & -stabilization



TYPHA LATIFOIA - CATTAIL

- Perennial herbaceous (1.5-3m)
- Accumulator of petroleum, chlorinated solvents & azatrines
- Phytoextraction & -accumulation



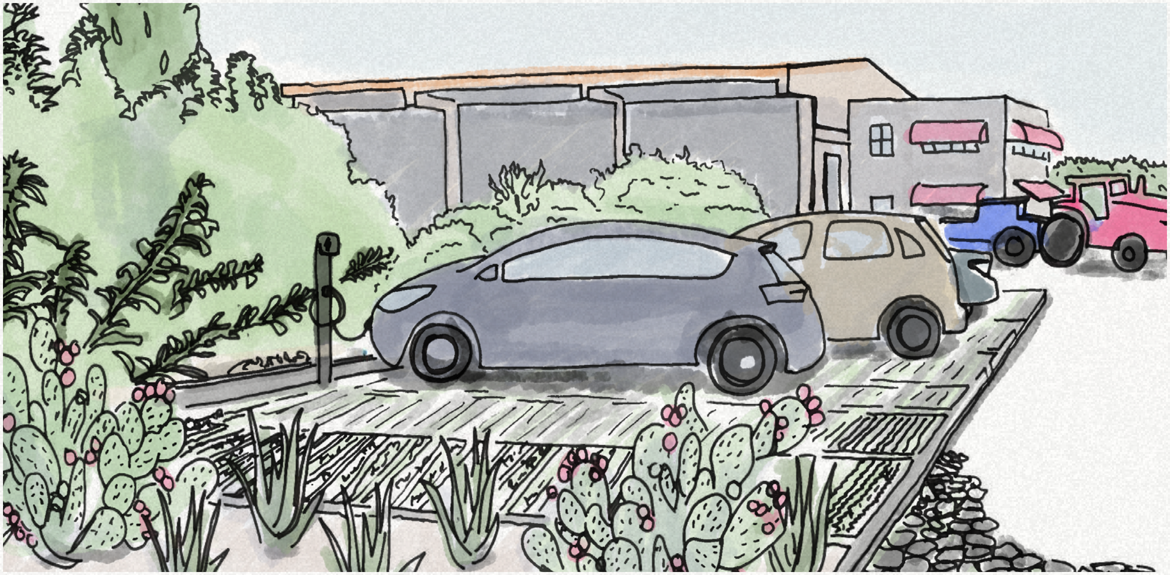
HELIANTHUS TUBEROSUS - JERUSALEM ARTICHOKE

- Herbaceous grass (10-90cm)
- Accumulator of mercury
- Phytodegradation & excluder
- Tolerant of heavy metal-toxicity

RAPHANUS SATIVUS - WILD RADISH

- Annual herbaceous plant (60-90cm)
- Accumulator of heavy metals and hydrocarbons
- Phytostabilization

IMPRESSIONS



SUSTAINABLE PARKING SPACES, INCLUDING PERMEABLE PAVEMENTS AND REMEDIATING GRASSES

AGROVOLTAICS WITH DIFFERENT PLANTING OPTIONS BASED ON PHASING PRINCIPLES

CONCLUSIONS

Examining the land use of the site and the activities that take place at the location, the presence of various heavy metals and chlorinated solvents is expected. As this contaminated site is situated in a primarily rural and industrial area, there is little demand for urban or social program. However, a variety of design interventions have presented themselves as spatial solutions to battle soil contamination and improve the ecological landscape. Based on the spatial configuration of the site and typology guidelines, the site is buffered from agricultural land use, and renewable energy production is introduced in the form of biomass production and agrivoltaics. Additionally, sustainable parking spaces, involving permeable pavements and phytoremediation grasses are introduced. Riparian structures and helophyte filters are introduced to prevent further dispersion and run-off contamination.

Based on the characteristics of the local soil and climate system, a selection of phytoremediating plant species is created, linked to the selected patterns. A variety of growth habits, root depths, and seasonality is created among these plants. All in all, the redesign of this site presents a multitude of opportunities for adding dense vegetation to contribute to regional GI, using plants with phytoremediating potential. Sustainable energy production, improved work environments, and protected agricultural produce are crucial co-benefits that give this redesign its value.

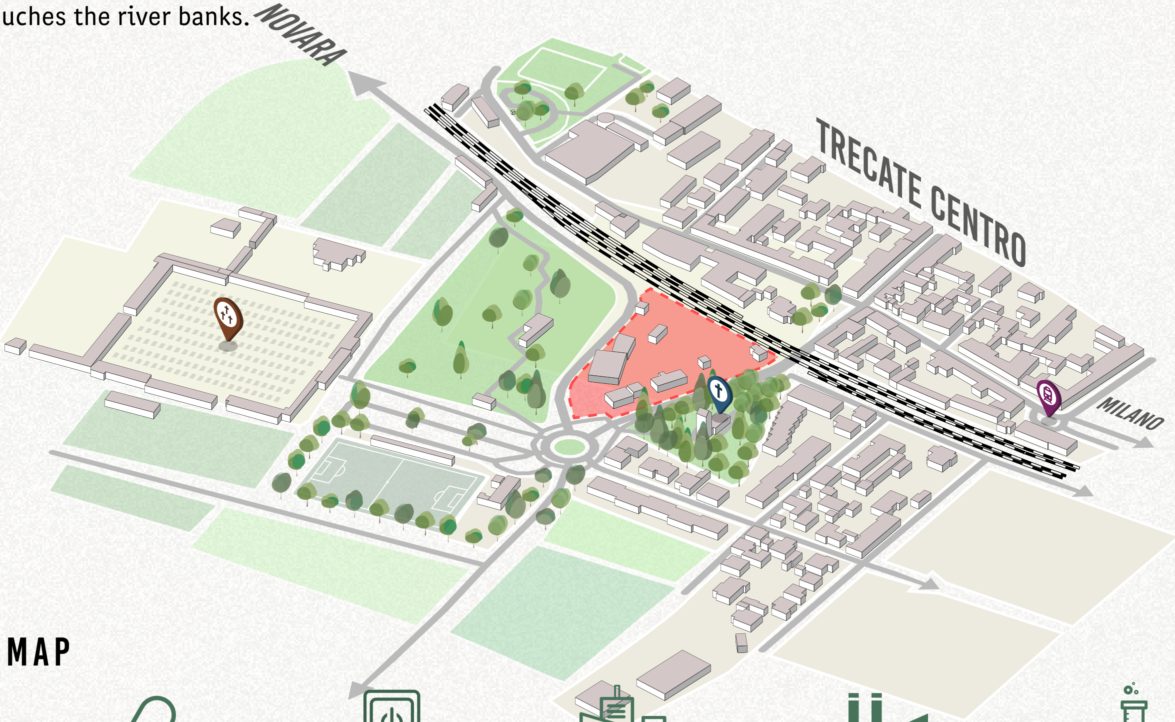
The next pages will present another contaminated site to be addressed using similar principles, fitted to the specific context.

REMEDIATION SITE II - INDIVIDUAL INDUSTRIES

TRECATE PHARMACEUTICALS

The former pharmaceutical factory is situated at the borders of the small town of Trecate. The municipality has an estimated population of 20,500 and is located between the city of Novara and the Ticino River. The town centre is relatively small, with limited commercial and economic activities as these are mostly concentrated in the larger nearby cities. Trecate is known for its industrial production. Nevertheless, the agricultural production of rice, fodder and livestock farming contributes significantly to the local economy. This is clearly visible in the surrounding rural landscape, which is characterised by vast fields, farmhouses and irrigation canals. Moving towards the east, we are approaching the Ticino River and the Polo Industriale San Martino, a large oil refinery that touches the river banks.

The former factory is situated on the southern border of Trecate. The site is encircled by train tracks from the north, creating a physical barrier between the remediation site and the city centre. Directly west of the site lies the Strada Provinciale 99, which separates the site from a biopark, a local animal shelter and the cemetery located behind. Although the SP99 is a provincial road, it is not heavily trafficked, as there are other major access routes to the town centre. The site is situated within 100 metres of a football club and church, which illustrates the strategic location for social and cultural urban functions. The location of the former pharmaceutical factory within Trecate provides a unique opportunity to explore the interplay between industrial and natural landscapes.

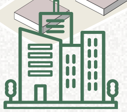


SITUATION MAP

AREA - 7.500 M²

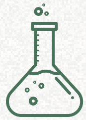
PHARMACEUTICALS PRODUCTION

CLOSED SITE



URBAN CONTEXT

INDUSTRIAL SITE



ORGANIC COMPOUNDS

POSITION WITHIN CORRIDOR

LOCATION CHARACTERISTICS

Soil type	Anthraquic Skeletic Cambisol	**Ground water depth**	Medium-high groundwater table
Soil salinity	Non-saline soil	**List of (possible) contaminants**	• Methanol • Ethanol • Aceton • Kaliumhydroxide • Nitric acid • Sulphuric acid • Talc • Palladium (Pd) • Platina (Pt) • Nickel (Ni)
Soil pH	±6.4		
Organic Carbon Density	24.9 kg/m³		
Climate	Humid subtropical climate		
Min. temperature	-5°C		

CURRENT USE & DESIGN GOALS

The spatial configuration of the factory site comprises several large factory buildings, warehouses, and administrative offices that were constructed over time as the facility expanded. The site covers a significant area of 7,500 sq. meters and is organized around a central courtyard with the main production buildings located around its perimeter. Smaller ancillary structures such as storage sheds and utility buildings are situated to the west of the site, while the main factory buildings occupy a location to the west of the perimeter. A high, walled perimeter currently surrounds the entire complex.

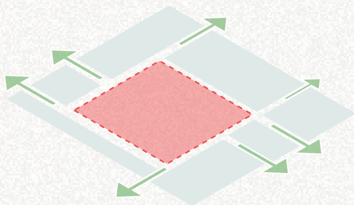
The factory was one of the production locations for a major pharmaceutical company. At the site, multiple pharmaceuticals and medicines were produced, including aciclovir, doxofylline, and inosine pranobex. The production processes of these pharmaceuticals required specialized equipment and facilities, which were housed in the various buildings on the site. In addition to the main production areas, the site also included warehousing and storage spaces, as well as administrative offices to support the operations. The production process required several different types of chemicals, which were mostly used as catalysts, indicators, additives, or acids. Poor storage management, leaking compounds, and spillage incidents have likely led to significant soil and groundwater contamination on the site, which will require thorough environmental remediation efforts before any future redevelopment can take place.

The location is situated within or in close proximity to an urban context, which presents an opportunity for the redevelopment to incorporate social functions and become a place where people can meet and socialize. To reinforce the relationship between the proud Piedmontese people and their famous agriculture, the site will be redeveloped into a community center focused on sustainable food production and agriculture. As this area is also very close to the city, as well as the proximity to the local park, sports, and church, this location could be of significant value. By remediating the site, a location suitable for future development can be created that will enable the site to reach its full potential.

DESIGN GUIDELINES

UTILIZING EXISTING STRUCTURE

INTRODUCING SOCIAL PROGRAM & FUNCTIONS



CONNECT TO THE LOCAL URBAN FABRIC

SITE IMAGES

POSSIBILITIES FOR REDESIGN

This contaminated site in Trecate offers a lot of possibilities for sustainable redevelopment. To create space for even more possibilities, the SP99 is rerouted to go around the biopark, connecting the contaminated factory site with the biopark. The biopark is loved by the local community but is not very intensively used. Online reviews of the site refer to the biopark as 'a hidden gem'. The lack of program, like playgrounds, calisthenics equipment, a café, or an ice cream shop is the only complaint that often reoccurs. Redevelopment and integration of the redeveloped factory could fulfill those needs, without the need for new construction.

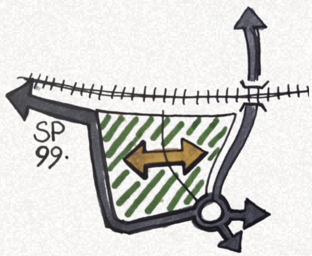
Using the existing structures of the old factory and redeveloping them into a community center, including classrooms, workshop spaces, office space, and a café or restaurant, would create the needed program for the biopark. With over 2,000 square meters of floor space, this program should be able to fit into the existing structures.

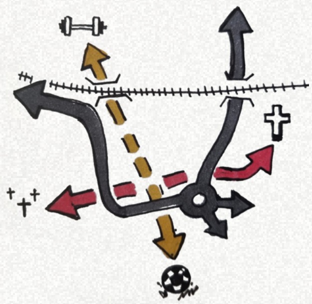
Along the northern site boundaries, a multimechanism buffer is planted. Heavy trains and intense train traffic lead to heavy metal contamination of the direct surroundings. Besides that, the air and noise pollution from the railroads are kept away from the community center, keeping the green oasis calm and tranquil.

Improving awareness of soil health and pollution, this site is transformed into a green and sustainable community center. The center focuses on sustainable food production with respect to the landscape and the soil. As the site is very contaminated and cannot directly be used for food production, this first happens in temporary elevated greenhouses. By elevating them and keeping the soil as free as possible, we permit phytoremediation grasses under the structure to remediate the contaminants. Community gardens around the site's perimeter, first need to be remediated to below a safe threshold concentration. First, flower gardens will be placed, remediating the soil to safe concentrations, before food production of tolerant and safe fruits and vegetables is reached.

The animal shelter in the biopark is extended with a petting zoo. Although not directly remediation contaminated soil, this function helps in creating a coherent center for sustainable food production and attracts kids and schools to connect to the site and the agricultural sector.

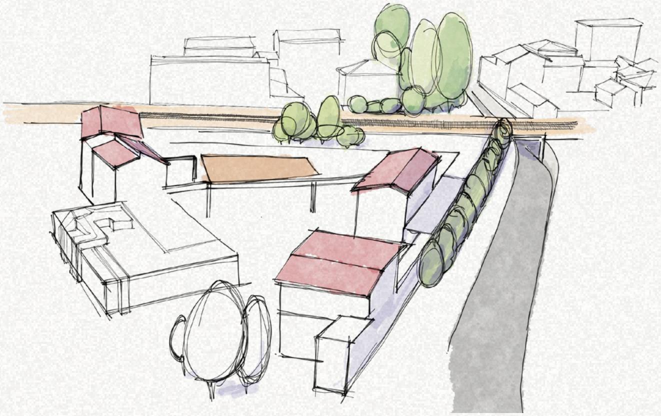
The factory's courtyard offers space for concerts, gatherings, marketplaces, or events. The introduced restaurant closes the food cycle, serving locally produced food, while attracting people to the site. By opening up a connection to the city center through a pedestrian tunnel underneath the train tracks, the site connects to the urban green structure and allows better connectivity to the sports center and historical city center.

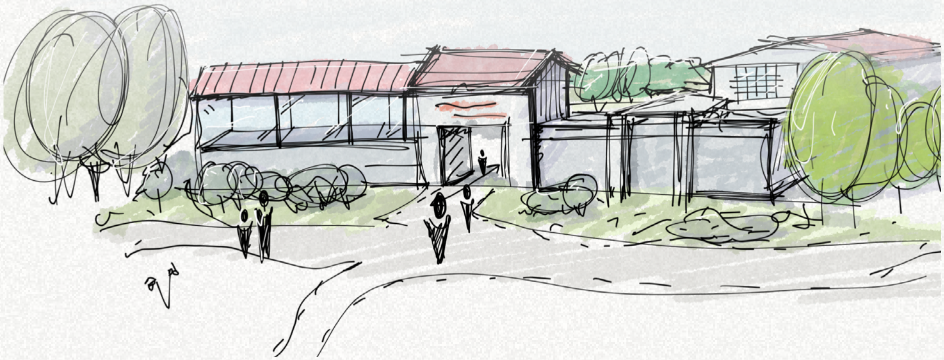




By breaking down the walls and gates surrounding the factory, the site opens up and connects better to the urban context, the biopark, and the agricultural landscape. Opening up the factory building and creating a gateway that directly connects the inner courtyard to the park further strengthens the relationship between the natural and urban landscapes.

The following pages give an overview of the proposed possibility for redesigning tgis brownfield. All used patterns are presented, as well as an extensive overview of the implemented vegetation.





DESIGN INTERVENTIONS

Temporary program

Community gardening

Buffer zones

Recreational park

Sustainable parking

Pocket parks

Structure transformation

ACCUMULATOR PLANTS OVERVIEW

FESTUCA ARUNDINACEA - TALL FESCUE

- Perennial grass (<165cm)
- Hyperaccumulator of arsenic, copper, lead & zinc
- Phytostabilization, -extraction, -degradation & rhizodegradation

POPULUS ALBA - WHITE POPLAR

- Deciduous tree (<20m), fast-growing
- Accumulator of arsenic, lead, copper, manganese and zinc
- Phytostabilization & phytoaccumulation
- Root depth of ±50cm

HIRSCHFELDIA INCANA - SHORTPOD MUSTARD

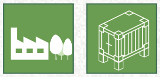
- Annual shrub (<1m), fast-growing
- Accumulator of Lead, Cadmium, Copper & Zinc
- Phytoextraction
- Fast-growing and fast-spreading

FESTUCA RUBRA - RED FALLOW

- Perennial herb (<20cm)
- Accumulator of phosphorus, nitrogen & PAHs
- Rhizodegradation & phytorextraction
- Low maintenance

URTICA DIOICA - STINGING NETTLE

- Herbaceous perennial plant (0.9 - 2m)
- Accumulator of PAHs and PCBs
- Rhizodegradation
- Valuable source for butterfly larvae, nettle extract can be used as pesticide/fungicide



TRIFOLIUM REPENS - WHITE CLOVER

- Herbaceous perennial plant (5-10cm)
- Accumulator of diesel, petrol, PCB & PAHs
- Rhizodegradation

PORTULACA GRANDIFLORA - MOSS ROSE

- Annual flower (<30cm)
- Hyperaccumulator of aluminium, copper, iron & zinc
- Phytoextraction
- Valuable food source for honeybees and butterflies

CALENDULA OFFICINALIS - MARIGOLD

- Herbaceous perennial (<80cm), short-lived
- Accumulator of cadmium & lead
- Phytoextraction
- Valuable food source for butterflies, edible and used in salads or as garnish

AXONOPUS COMPRESSUS - CARPET GRASS

- Perennial grass (<15cm)
- Accumulator of lead, zinc, copper, cadmium, PAHs
- Phytoaccumulation
- Useful as permanent pasture or groundcover

SCIRPUS MUCRONATUS - BOG BULRUSH

- Perennial herb (20 - 30cm)
- Accumulator of petrol hydrocarbons
- Phytoaccumulation
- Considered as a weed in rice fields

LOLIUM PERENNE - PERENNIAL RYEGRASS

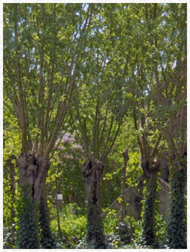
- Herbaceous grass (10-90cm)
- Accumulator of pentachlorophenol, Cd & Hg
- Fast growing, high yields
- Used for animal fodder or biomass
- Phytoextraction & rhizoextraction

IRIS X GERMANICA - BEARDED IRIS

- Annual flowers
- Hyperaccumulator of Aluminum, Arsenic, Cadmium, Copper, Flourine, Manganese, Zinc
- Rhizofiltration

POPULUS NIGRA - BLACK POPLAR

- Deciduous tree (25-30m)
- Accumulator of heavy metals & hydrocarbons
- Phytoextraction & -accumulation



SALIX ALBA - WHITE WILLOW

- Deciduous tree (10-30m)
- Accumulator of petroleum hydrocarbons
- Phytoextraction & -accumulation
- Useful for basket-making

POPULUS DELTOIDES X TRICHOCARPA - HYBRID POPLAR

- Type/habit (size/height), growing speed
- Accumulator of petrol hydrocarbons
- Phytodegradation, -extraction & -stabilization, Rhizodegradation
- Fast growing

SALIX DASYCLADOS - SHRUB WILLOW

- Woody perennial (3-4m), fast-growing
- Accumulator of petrol hydrocarbons
- Phytoextraction & rhizodegradation

VEGETATION SELECTION

As the site has a variety of potential contaminants and offers a lot of spatial opportunities for redevelopment, this results in a wide range of appropriate vegetation. The selection of the plant species is based on the database created using scientific literature. This database can be found in the appendix of this thesis. To streamline the vegetation selection process, a simple and accessible workflow is used, which is visualized on the next page.

First, the database is filtered on the contaminant type. In this case, that results in several types of heavy metals, as well as organic contaminants used in the pharmaceutical production process. Based on the local climate information, the plant species are filtered on hardiness. Using information on groundwater tables, soil salinity, and soil type, the selected plants are further evaluated. Then, the nativity of these plants is checked in the same database, and confirmed by checking their invasive status online. From the resulting vegetation, a variation in root depths and seasonality is pursued. Potential co-benefits of the remaining plants are researched using literature.

FICUS CARICA - COMMON FIG

- Woody perennial (<4m)
- Tolerant of petrol hydrocarbons
- Tolerance
- Fruits can be grown and consumed in (slightly) contaminated soils

CITRUS AURANTIFOLIA - KEY LIME

- Woody perennial (<5m)
- Tolerant of petrol hydrocarbons & several heavy metals
- Tolerance
- Fruits can be grown and consumed in (slightly) contaminated soils

SOLANUM LYCOPERSICUM 'COSTOLUTO FIORENTINO' - BEEFSTEAK TOMATO

- Perennial herbaceous (0.2 -1.8m)
- Tolerant of petrol hydrocarbons & heavy metals
- Tolerance
- Fruits can be grown and consumed in (slightly) contaminated soils, sow together with Marigold as nat. pesticide

CAPSICUM ANNUUM - SWEET PEPPER

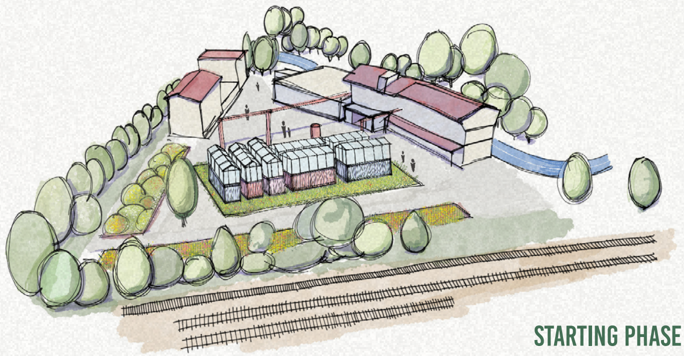
- Perennial herbaceous (0.3 -1.2m)
- Tolerant of petrol hydrocarbons & several heavy metals
- Tolerance
- Fruits can be grown and consumed in (slightly) contaminated soils

PHASING

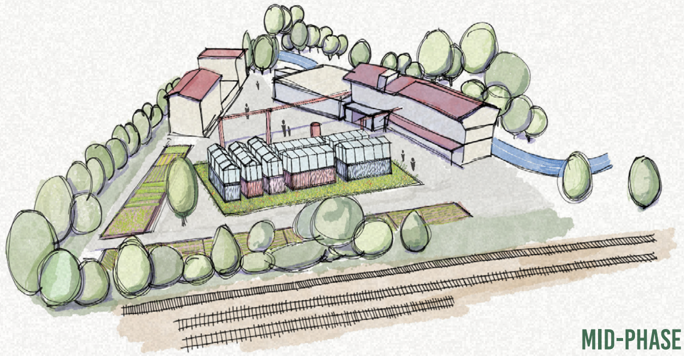
Phasing is extremely important when using long-term solutions such as phytoremediation. During the redevelopment of the site, used patterns can change over time. This case of the Trecate pharmaceutical factory provides a clear example.

The site is redeveloped into a community center, focused on sustainable food production and gardening. As the initial contamination levels are expected to be relatively high, the soil does not allow for safe food production. In the intial phase, the community gardens will be used for growing flowers. When safety threshold values are met, in mid-phase the flowers can be substituted for agricultural crops.

Similarly, in the initial and mid phase, temporary elevated program is placed on the site. Being elevated over the soil, they allow phytoremediating grasses and herbs to grow and decontaminate the soil. After reaching safe contamination levels in the final stage of the process, this temporal program can be replaced with permanent redevelopment.



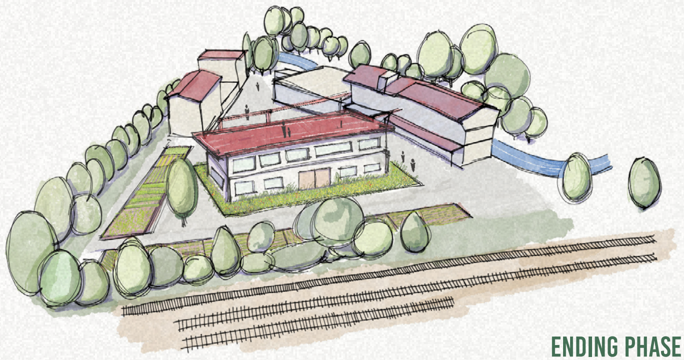
STARTING PHASE



MID-PHASE

VEGETATION SELECTION WORKFLOW

1. FITTING THE CONTAMINANT & LOCAL CLIMATE
2. INVASIVENESS & NATIVITY
3. ROOT DEPTH & SEASONAL VARIATION
4. CO-BENEFITS & SOCIO-ECONOMIC OPPORTUNITIES



ENDING PHASE


EDU CENTER
MARKET
GARDEN
APERITIVO

SUSTAINABLE FOOD CENTER

This visualization shows a possible outcome of this sustainable food center. The center houses eve-rything to showcase innovation and sustainability within the food sector. The factory's inner court-yard is transformed into a marketplace where local farmers can sell their products directly to the community. The greenhouses make it possible to grown fruits and vegetables throughout the entire year without interacting with the contaminated soils. Introducing restaurants or cafés in the former factory structures allow for closing the food cycle and have local consumption. Office spaces overlooking the new community center offer space for new innovative companies. The entire areas breaths life and nature.

The multimechanism buffers along the railroad track disconnect the site from its former industrial character. It turns the location into a green oasis, even though its directly bordering the railroads. It also buffers the center and the community gardens from soil contamination from the trains and catches the airborne pollutants to improve the micro-climate and its air quality. Opening up the walls that used to enclose the factory site results in permeability and accessibility, while the remaining structures still give an enclosed and cozy atmosphere. The provincial road is transformed into a running or cycling track, connecting a healthy and sporty lifestyle to the innovation center.

TOUCHING UPON FARM LIFE

Although the food innovation center is accessible for everyone, special attention is aimed at the younger generation. The biopark currently houses an animal shelter and several ponds with turtles. Adding a petting zoo, where children can learn and interact with farm animals would be a valuable addition to the food center. The current functions within the biopark can remain, and more functions are added to further develop the site. As the site is remediated and ready for new permanent development, this has opportunities to add a school, directly connected to the park, away from major roads, close to the agriculture and well accessible by bike or as a pedestrian from the city center or by car.

CONCLUSION

The more urban situation of this second remediation site offers a wide range of redevelopment options. As the site is tightly connected to the town and its community, introducing social and communal program is valid. This southern part of the town is isolated from the city center by the railroad tracks and a gathering place for this local community was missing. Additionally, the neighboring recreational park is not exploiting its full potential due to a lack of program. As the structures and buildings from the factory are still intact, a transformation would be a sustainable and obvious solution. Creating a community center targets the local residents of the neglected southern neighborhoods of Trecate and adds program to the underused biopark.

The redesign is composed using a wide range of patterns. Combining this with a lot of different contaminant types results in a wide range of needed vegetation. As this site is more actively used in comparison to the previous design location, more attention is needed to selecting tolerant plant species and the phasing of the redevelopment. This site is also less connected to the existing regional landscape structures. To integrate this site into large-scale GI, the surrounding areas need to be redesigned as well. Densification of the biopark, greener street profiles, vegetation buffers, and riparian green structures are needed to ensure ecological connectivity.

These two showcase sites have proven the value of the integral design approach. From the regional scale of Piemonte, the design approach has systematically zoomed in. First by selecting an optimal location for new GI planning, then by identifying the contaminated sites that are to be integrated into the corridor, redesigning them, and eventually even selecting the appropriate vegetation types. Although the designs are not in extreme detail, the approach has helped to quickly establish design options and can be used as a foundation for selecting and redesigning contaminated sites for improved landscape connectivity.

07

CONCLUSION & DISCUSSION

CONCLUSION

This thesis aimed to develop a systematic and data-driven design approach for GI, focussing on the integration of phytoremediating practices in regional scale development. Based on a case study in the Piedmont Region, Italy, a design approach is developed that uses a variety of digital analyses and assessment tools to optimize design efforts across different scales. Showcasing this approach in the study area presents the value and potential of integrating contaminated sites into regional green structures and allowing the implemented vegetation to contribute to both landscape connectivity and sustainable soil remediation.

The comprehensive framework incorporates data-driven methodologies into every aspect of the design process, resulting in systematic and well-informed design decisions on all faced challenges. By systematically working across the different scales, optimization is done on each of the challenges faced, ranging from optimized location selection on the regional scale to effective and compatible vegetation selection. Each element of the framework is based on data analysis, design, and assessment, further contributing to effectivity and reproducibility. Additionally, the systematic and modular nature of the approach allows for each segment to be adapted, expanded, and fit into other contexts without necessitating adaptations to the approach as a whole. The design approach was developed iteratively through application within the study area. By methodically addressing the challenges faced during optimization efforts on each spatial scale, the design approach emerged organically. The approach streamlines and optimizes design efforts on all spatial scales, ranging from regional natural landscapes to vegetation selection on the smallest scale.

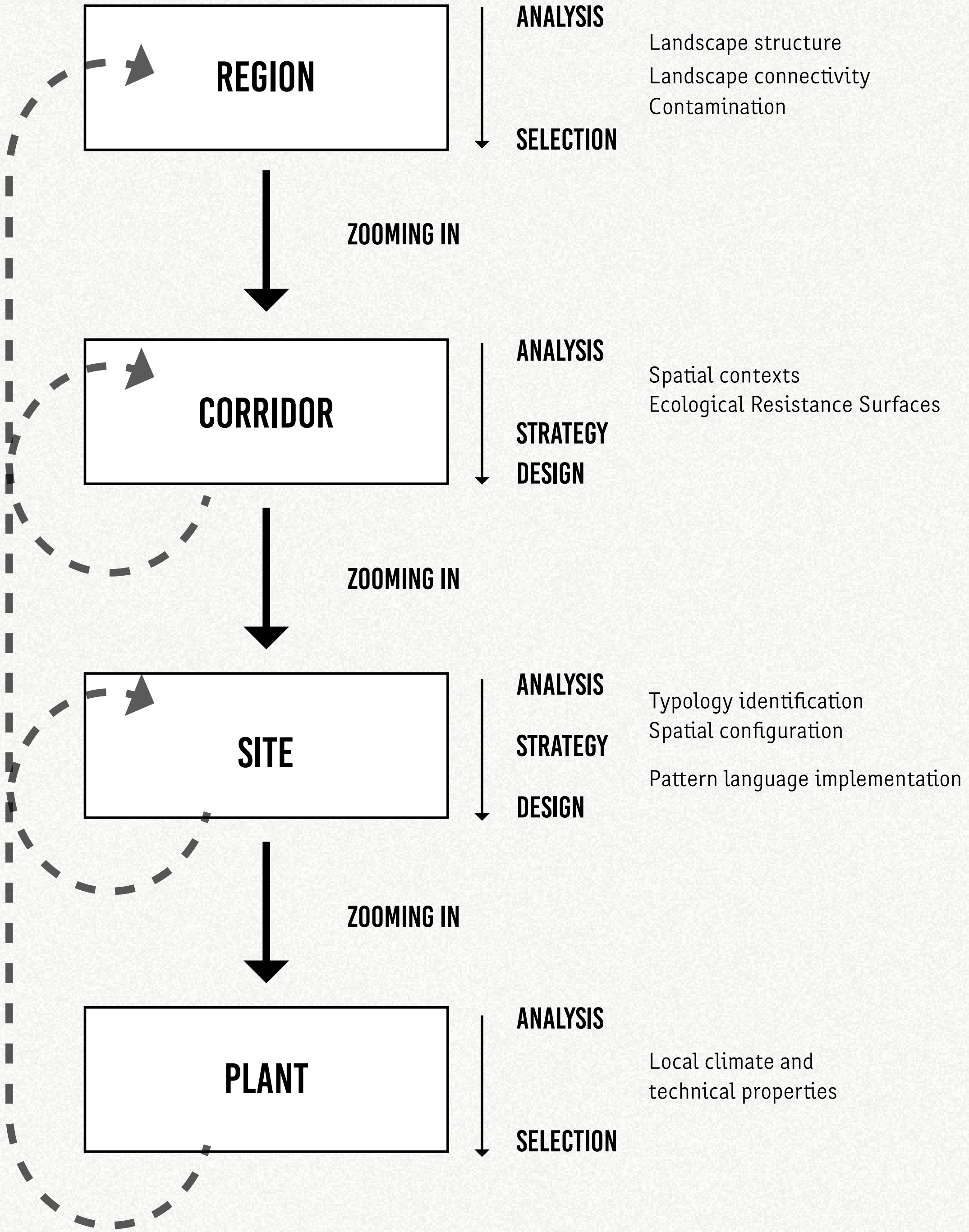
METHODS AND QUESTIONS

Firstly, landscape fragmentation on the regional scale is addressed by assessing the landscape connectivity. Based on spatial data from the CLC 2018, the regional green structures are mapped. The structure is assessed by conducting MSPA, resulting in 203 relevant ecological core areas. These core areas were used as ecological sources in a graph-theoretic network assessment to quantify landscape connectivity and identify potential connections in the natural landscape that have the highest potential impact on the connectivity of the regional landscape. Comparison between the spatial distribution of high-impact connections and contaminated sites resulted in multiple potentially interesting corridor locations. The area around Novara, between the Sesia en Ticino Rivers, was selected for further design as this area has both high-impact connections and multiple contaminated sites that could be integrated into this GI.

To design the corridor into the landscape of the selected corridor location, multiple design strategies were developed, based on best-practice references and literature. The strategies aim to improve landscape connectivity and provide ES to the surrounding landscape. These design strategies, or guidelines, allow for quickly establishing design options for the corridor path. Multiple design options were created within the design area, based on the strategies. Using an ERS model, the design options are assessed. The ERS results lead to an improved and optimized corridor path, connecting the ecological cores and the contaminated sites in between. The designed corridor path incorporates 9 different contaminated sites and spans over 35 kilometers.

The optimized corridor path is assessed using the same methodology, and the remaining high-resistance areas are identified. These options require additional attention and solutions to overcome ecological resistance during design and implementation. Finally, the corridor path is translated into a network of various individual forest patches to ensure landscape variation and improve ecosystem health and resilience.

To integrate the contaminated sites into the GI, first, an assessment of the contaminated sites is crucial. As the properties of the contaminated sites are highly variable,


REGION
ANALYSIS
Landscape structure
Landscape connectivity
Contamination
SELECTION
ZOOMING IN
CORRIDOR
ANALYSIS
Spatial contexts
Ecological Resistance Surfaces
STRATEGY
DESIGN
ZOOMING IN
SITE
ANALYSIS
Typology identification
Spatial configuration
STRATEGY
Pattern language implementation
DESIGN
ZOOMING IN
PLANT
ANALYSIS
Local climate and
technical properties
SELECTION

a typology is created based on spatial data on these sites, including site size, primary land use, the presence of buildings or structures, and the operability state. This data is gathered for 171 contaminated sites in the corridor's direct surroundings, using regional and European databases, supported by imagery and a CNN trained in image classification.

Using a k-means clustering method, a typology of five different types of contaminated sites is created based on the spatial data. The typology includes industrial giants, individual industrial sites, urban incidents, peri-urban plains, and contaminated agriculture. By creating design guidelines per typology, the creation of quick and targeted designs becomes easier and more accessible.

To further streamline the redesign process, an open-ended pattern language is created. The pattern language consists of 15 patterns, based on spatial opportunities and potentials. The patterns are created using design explorations, best-practice references, and literature. Information on space, land use, and vegetation requirements, as well as the remediation strategy and phasing, are presented for each pattern. To test and showcase the patterns, they are implemented in two of the contaminated sites along the designed green corridor.

Plant species and vegetation types are not included in the presented patterns as these can be highly flexible and be appropriated to the explicit sites where they are implemented. Based on the literature, a database is created containing information on approximately 760 unique plant species showing phytoremediating potential. The database includes information on the addressed contaminant, growth habits, hardiness, and nativity.

To test the implementation and selection workflow for the vegetation, the same contaminated sites as a test case. These sites are mapped on soil characteristics, climate properties, and contamination using regional and European datasets. Empirically, a selection workflow emerged where compatibility with the contaminant and the proposed program, the nativity and invasiveness, the variation in root depth and seasonality, and the potential socio-economic benefits are included.

RECOMMENDATIONS AND RELEVANCE

The proposed design methodology is data-driven and is primarily based on geospatial data. However, this data is not always available or satisfactory. Incorporating field experiments, pilot studies, and on-site studies are needed to validate and improve the proposed methods. As the approach is aimed to improve collaboration and communication between stakeholders in complex multi-scalar design challenges, it is crucial for the validation of this approach to be tested and assessed in practice. Furthermore, the scalability of the approach presents opportunities for it to be used on other scales. Using a similar framework for enhancing urban biodiversity and ecological connectivity on the city scale could be valuable.

All in all, this thesis demonstrates that integrating phytoremediation practices within regional GI planning is possible through a comprehensive multi-scalar design approach. By applying a comprehensive framework both soil contamination and landscape fragmentation can be effectively addressed. By employing a data-driven approach that spans from the regional to the micro-scale, it is possible to make well-informed, strategic design decisions to enhance landscape connectivity, ecosystem health, and soil status.

PERSONAL REFLECTION

My master's thesis focuses on the relationships between ecological landscapes and soil contamination and presents a systematic design approach that poses sustainable solutions to these environmental problems across different spatial and temporal scales. As industrialization and urbanization have a major negative impact on the state of nature, it is crucial to try and revitalize the ecosystems surrounding us. Landscape fragmentation in particular is one of the most severe causes of ecological decline and biodiversity loss. At the same time, a lot of areas have become contaminated due to unsustainable practices and are in severe need of remediation. By analyzing nature and ecological structures from a network perspective, I am identifying the ideal locations for reinforcing the ecological network, i.e. finding locations where new green structures create the most intensely used new ecological connections. The results from the landscape connectivity analysis are compared to the spatial distribution of contaminated sites. By redesigning and redeveloping The specific contaminated sites and integrating them within the regional natural landscape sites with the use of phytoremediation, a new landscape is realized that contributes to both aforementioned issues: remediation of local contaminated sites and strengthening the ecological network on the regional scale.

The region of Piemonte, Italy, is used as a study area to showcase the approach developed during the thesis. The region of Piemonte shows a lot of possibilities for ecological reinforcement, as well as the remediation of contaminated sites. The region is heavily industrialized, which leads to very high concentrations of various types of pollution. The cities of Turin, Ivrea, and Biella are among the most heavily industrialized cities in Italy, producing a ton of soil, water, and air pollution. Agricultural production, primarily rice production, is a second characteristic element of Piemonte. The risotto rice from Vercelli and Arborio are famous worldwide. The enormous monotonous, agricultural landscape used for rice production is disastrous for the biodiversity and ecosystems of the area. All in all, this research territory shows a lot of possibilities for developing and testing an approach to combine local soil remediation and green infrastructure design. The main focus of the thesis was creating a systematic methodology to identify, classify, and design for ecological values in these contaminated landscapes throughout different scales.

With the presented approach I aimed to spatialize the environmental challenges of today (and the future) while combining research and design to explore valuable spatial solutions. Analyses of the ecological network were guiding for the selection of my design locations and played a major role in planning on the regional scale. At the local scale, I used a design perspective to create spatial interventions that could tackle soil contamination with phytotechnologies. Soil contamination and phytotechnologies are extremely technical topics. Rightful implementation of these concepts requires a lot of data and knowledge about site-specific characteristics of contamination concentration, types, depths, the local (micro)climate, soil properties, etc. Gathering and processing these data is essential for this project and guiding the selection of design solutions. Besides technical considerations, these redeveloped spaces have an impact on their spatial environment. Being able to combine the technicalities of phytoremediation with the designing of valuable spaces that fit the local environment and have socio-economical value is a major driver of the project. Brainstorming, sketching, and designing possible combinations of socio-economical functions and phytoremediation contributes to new creative options for implementing phytoremediation in practice. With this in mind, I think that this approach touches the core of urbanism: spatializing challenges while combining (multidisciplinary) research with design to get to innovative solutions.

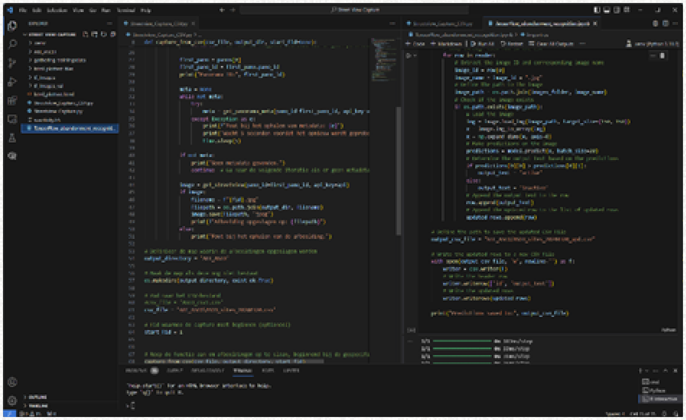
Throughout my thesis, I tried following a systematic approach, which is always as replicable and retraceable. Especially since I want to focus on the methodology rather than the actual case, I think it is important to be as transparent as possible. This meant using as much open-source software as possible, using data that would also be accessible in other contexts, and being as objective as possible when making (design) decisions.

Although it was a noble goal, this clinging to a systematic and data-driven methodology also showed its downsides. I first encountered this in the data availability between different regional and local agencies and institutions. Gathering and combining the right data from all these different institutes turned out to be very time and energy-consuming. Especially when working with foreign territories and languages.

Another challenge arose in the processing of all this data when using computational analyses. Utilizing more and more data in spatial research also meant longer processing times. On multiple occasions, I was forced to restructure, simplify, and rescale my data to be able to run my analyses within an acceptable timeframe. This was sometimes at the expense of the accuracy or quality of the calculations.

However, the most interesting manifestation of this stubbornly clutching onto the systematic approach occurred while classifying the different remediation sites. I wanted to categorize the typical contaminated sites to develop design interventions that would fit these different typologies. To do this, I established a list of concrete assessment criteria, so I could statistically cluster them based on their values for all these criteria. I tried to make sure that a lot of these criteria could be analyzed by using open-source data to make sure that transferability and replicability are as high as possible. One of these criteria was the operability state of the sites, i.e. see if the location is still functioning or that it was already vacant or abandoned. This data was not available for my research territory, which forced me to map this by hand. Using Google StreetView imagery, I tried to determine if these sites were still operational. As this was not always directly visible, I had to make assumptions. Besides that manually mapping from static images is very prone to bias, which is something that I tried to avoid as much as possible.

To surpass this, I tried to minimize my bias and find creative ways to do so. The 'StreetView case' is a great example of that: as I couldn't bear to give this classification of operational status myself, I tried training a Neural Network with image recognition to classify these sites for me. I trained the AI with data from other areas, to make the classification more accurate. In this way, I bypassed my personal bias. However, the data that derived from the AI also comes with some sidenotes, as the AI is not 100% accurate, is trained using data from different locations, cultures, and landscapes, and I could not verify the correctness of the training data. Although the approach is still flawed, I think it is a good first step into a new way of handling data which, when updated and improved, can be very valuable in a variety of research fields.

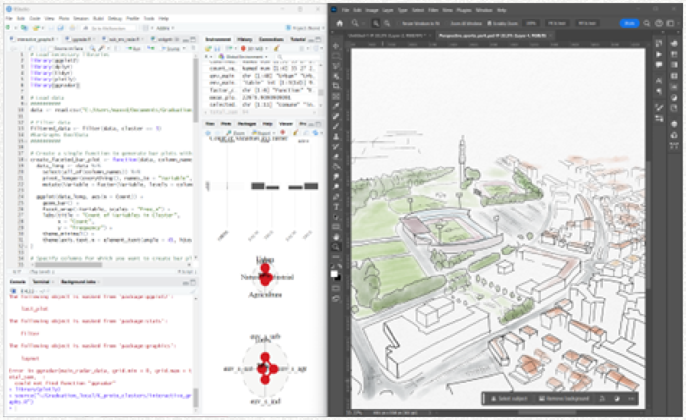


CHALLENGES ALONG THE WAY INTRODUCED ME TO CODING WITH R, PYTHON AND TENSORFLOW TO TRY AND OVERCOME DIFFERENT KINDS OF ISSUES. I THINK THIS ARE SOME VALUABLE SKILLS THAT I HAVE OBTAINED DURING THE THESIS.

My mentors have played a major role in role in the way my thesis took shape. They took their time to introduce me to compelling literature, useful (geo)data libraries, and interesting design and research methods that were unknown to me before. As inquisitive as I am, I tried following all of the small threads handed to me by my mentors. This lead to various adventurous insights and methods; the GIS-based spatial analyses, K-means cluster methods, and hierarchical structuring of my remediation site typologies being just a few of them. However, I tend to try and decipher all of these ideas completely and tend to get lost in all the literature easily. It always takes me a few days to snap out of it and leave the possible extra possibilities for what they are. In the end, I think this has cost me a lot of time. At the same time, however, I think that they are very valuable for my thesis and my personal development. These insights required me to switch between different fields of expertise all the time, and forced me to learn new skills to make use of them: I learned to code in R and Python, invested in learning more about statistics and cluster methods, learned the basics of building and training a neural network for image recognition, etc.

While my mentors have helped me a lot with restructuring my products, streamlining my research and design methodology, and sharpening my argumentation and reasoning, I think that their way of stimulating creativity in the methodology and use of different tools has been the most valuable for me.

Over the last few months, I have been discovering a wide range of new concepts and approaches that enthused me. It seemed like every week new theories and tools came on my path, which I wanted to try out for myself and incorporate into my project. However, there is only so much time to work on this beautiful project, and deadlines have to be met. I would have loved to delve deeper into the subject matter and try out more design and research approaches if there was more time. I am very interested in applying the presented approach on different scales and contexts. Using landscape connectivity on the city scale and refining urban green structures, while incorporating phytoremediation to protect and buffer contamination from intense traffic is an example of an application in which I see potential for this approach.



MY PREFERRED METHODS ARE A COMBINATION OF DATA-PROCESSING AND TRADITIONAL DESIGNING/SKETCHING.

I'm proud to present the results and conclusions of my thesis. Especially how theories from other disciplines are incorporated into this spatial design approach is something that I am particularly proud of. An example of this is the graph-theoretic connectivity approach, which is a popular concept within computer and network science but has not made its way into spatial design just yet. The majority of tools and theories I used were unknown to me before this thesis. I have learned a lot over the past months, and have proven to be able to quickly select, identify, and adopt new theories in my workflow. I hope I can inspire researchers, spatial designers, students, policymakers, and whoever else is reading my thesis that inter-disciplinary and multi-scalar design approaches are of huge importance and lead to new and creative solutions for the spatial problems that we face.

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09

APPENDIX

PHYTOREMEDIATING VEGETATION

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Abutilon avicennae	Indian Mallow	Explosives	TNT	Herbaceous
Abutilon theophrasti	Velvet leaf	Heavy Metals	Cd	
Acacia cana	Boree	Heavy Metals	Se	Tree
Acacia farnesiana	Sweet acacia	Heavy Metals	As	
Acacia mangium	Mangium, Black Wattle	Heavy Metals	Pb	Tree
Acacia pycnantha	Golden Wattle	Heavy Metals	Cu, Zn, Pb	
Acanthus ilicifolius L.	Holly-leaved acanthus	Heavy Metals	Cd	
Acer platanoides	Norway Maple	Petroleum	BTEX	Tree
Acer rubrum	Red Maple	Radionuclides	226Ra	Tree
Acer rubrum	Red Maple	Heavy Metals	Cs, Pl	Tree
Acer saccharinum	Ag Maple		PCB, TCE	
Achillea millefolium	Yarrow	Heavy Metals	Cd	
Acorus calamus	Sweet Flag	Explosives	TNT	Herbaceous
Acorus calamus	Sweet Flag	Pesticides	Atrazine	Wetland
Aeluropus lagopoides	Mangrove grass	Heavy Metals	Cd, Cu, Pb, As	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation	8–11	India	Chang et al., 2003 Lee et al., 2007
Accumulator			Vandenhove et al., 2004
Hyperaccumulator	9–10	Australia	Baker and Reeves, 2000 McCray and Hurwood, 1963
Accumulator			1) Alcantara-Martinez N, Guizar S, Rivera-Cabrera F, Anicacio-Acevedo BE, Buendia-Gonzalez L, Volke-Sepulveda T. Tolerance, As uptake, and oxidative stress in Acacia farnesiana under arsenate-stress. Int J Phytoremediation. 2016;18(7):671-678. doi:10.1080/15226514.2015.1118432
Excluder; Accumulator	9+	Australia	1)(Phyto Textbook) Meeinkuirt, W., Pokethitiyook, P., Kruatrachue, M., Tanhan, P., and Chairyarat, R. 2012. Phytostabilization of a Pb-contaminated mine tailing by various tree species in pot and field trial experiments. International Journal of Phytoremediation 14 (9), pp. 925-938.
Accumulator			1) Nirola R, Megharaj M, Aryal R, Naidu R. Screening of metal uptake by plant colonizers growing on abandoned Cu mine in Kapunda, South Australia. Int J Phytoremediation. 2016;18(4):399-405. doi:10.1080/15226514.2015.1109599
Accumulator			1) Shackira AM, Puthur JT. Enhanced phytostabilization of Cd by a halophyte-Acanthus ilicifolius L. Int J Phytoremediation. 2017;19(4):319-326. doi:10.1080/15226514.2016.1225284
Degradation	3–7	Europe	Cook and Hesterberg, 2012 Fagiolo and Ferro, 2004
Extraction	3–9	USA	ITRC PHYTO 3 Pinder et al., 1984
Accumulator	3–9	USA	1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
N/A			1) Ferro, A., Chard, B., Gefell, M., Thompson, B., and R. Kjelgren. 2000. "Phytoremediation of Organic Solvents in Groundwater: Pilot Study at a Superfund Site" . In: G. Wickramanayake, A. Gavaskar, B. Alleman, and V. Magar (eds.) Bioremediation and Phytoremediation of Chlorinated and Recalcitrant Compounds, p461-466. Battelle Press, Columbus, Ohio.; Ferro, A., Kennedy, J., Kjelgren, R., Rieder, J., and S. Perrin. 1999. "Toxicity Assessment of Volatile Organic Compounds in Poplar Trees" . International Journal of Phytoremediation. 1(1): 9-17
Accumulator			1) Institute for EnvFemental Research and education (IERE). (2003 January). Vashon Heavy Metal Phytoremediation Study Sampling and Analysis Strategy (DRAFT). http://www.superorg.net/archive/proposal/plant_species_phyto.pdf
Degradation	3+	Asia	Best et al., 1999
Degradation or hydraulic control	3+	Asia	Marecik et al., 2011 Wang et al., 2012
Accumulator			1) Abbas ZK. Rhizospheric soil enzyme activities and phytominimg potential of Aeluropus lagopoides and Cyperus conglomeratus growing in contaminated soils at the banks of artificial lake of reclaimed wastewater. Int J Phytoremediation. 2017;19(11):1017-1022. doi:10.1080/15226514.2017.1319326

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Aeschynomene indica	Indian Joint Vetch	Explosives	TNT	Herbaceous
Agapanthus africanus	Lily-of-the-Nile	Petroleum	Unspecified	Perennial
Agropyron cristatum	Crested Wheatgrass	Petroleum	TPH	Herbaceous
Agropyron desertorum cv. Hycrest	Crested Wheatgrass	Chlorinated Sol-vents	Pentachlorophenol	Herbaceous
Agrostis capillaris	Common Bent, Colonial Bent, Browntop	Heavy Metals	Cu	
Agrostis capillaris L.	Bentgrass	Heavy Metals	Al, As, Pb, Mn, Zn	Herbaceous
Agrostis castellana	Highland Bent Grass	Heavy Metals	Al, As, Pb, Mn, Zn	Herbaceous
Agrostis delicatula	Bentgrass	Heavy Metals	Zn, As, Cu, Mn	Herbaceous
Agrostis exarata	Spike Bentgrass	Heavy Metals	As, Pb, Cs	Herbaceous
Agrostis scrabra	Rough Bentgrass	Heavy Metals	Pb, Cs	Herbaceous
Agrostis tenuis	Bentgrass	Heavy Metals	As, Cu, Pb, Zn	Herbaceous
Aizoon hispanicum L.	Spanish aizoon	Heavy Metals	Pb, Zn, Cu ,Cd	
Alisma subcordatum	Water Plantain	Explosives	RDX	Wetland
Allium schoenoprasum	Chives	Heavy Metals	Cd	
Alnus glutinosa	Black Alder	Petroleum	MOH	Tree/Shrub
Aloe barbadensis	Aloe	Heavy Metals	Pb, Total petroleum hydro-carbons	
Alopecurus pratensis	Meadow Foxtail Grass	Radionuclides	90Sr, 137Cs	Herbaceous
Althea rosea cavan	Hollyhock	Heavy Metals	Ni	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation		Asia, Africa	Lee et al., 2007
Tolerance	8–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Degradation	3+	Asia	Cook and Hesterberg, 2012 Muratova et al., 2008
Degradation	3+	Asia	Ferro et al., 1994 ITRC PHYTO 3
Tolerant			1) (Phyto Textbook) Bes, C. M., Jaunatne R., and Mench M. 2013. Seed bank of Cu-contaminated topsoils at a wood preservation site: impacts of Cu and compost on seed germination. EnvFemental Monitoring and Assessment 185 (2), pp. 2039-2053.
Accumulator, Hyperaccumulator			1) Phytoremediation of Radio-nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm-Zn 2) The University of Texas. http://wildflower.org/explore/
Accumulator			1) McCutcheon & Schnoor 2003, Phytoremediation. New Jersey, John Wiley & Sons, page 898.
Accumulator	4–10	Southwestern Europe, North Africa	Gomes et al., 2014
Accumulator, Hyperaccumulator			1) The University of Texas. http://wildflower.org/explore/
Hyperaccumulator, Accumulator			1) The University of Texas. http://wildflower.org/explore/
Excluder	3–10	Asia	Alvarenga et al., 2013 Dahmani-Muller et al., 2000
Accumulator			Midhat L, Ouazzani N, Esshaimi M, Ouhammou A, Mandi L. Assessment of heavy metals accumulation by spontaneous vegetation: Screening for new accumulator plant species grown in Kettara mine-Marrakech, Southern Morocco. Int J Phytoremediation. 2017;19(2):191-198. doi:10.1080/15226514.2016.1207604
Degradation	3–8	North America	Kiker and Larson, 2001
Hyperaccumulator, Accumulator			1) Khadka, U., Vonshak, A., Dudai, N., Golan-Goldhirsh, A. (2003), Response of Alliium schoenoprasum to Cd in hydroponic growth medium. In COST Action 837 â€œWorkshop on Phytoremediation of toxic metals.â€ Stockholm, Sweden, June 12-15, 2003. Retrieved March 10, 2004 from http://lbewww.epfl.ch/COST837/abstracts_stockholm/posters.pdf
Degradation	3–7	Europe, Africa	Tischer and Hubner, 2002
Accumulator			Escobar-Alvarado LF, Vaca-Mier M, López-Callejas R, Rojas-Valencia MN. Efficiency of Opuntia ficus in the phytoremediation of a soil contaminated with used motor oil and Pb, compared to that of Lolium perenne and Aloe barbadensis. Int J Phytoremediation. 2018;20(2):184-189. doi:10.1080/15226514.2017.1365332
Extraction	4–9	Europe, Asia	Coughtery et al., 1989 ITRC PHYTO 3 Vasudev et al., 1996
Accumulator, Hyperaccumulator			1) Cay S, Uyanik A, Engin MS, Kutbay HG. Effect of EDTA and Tannic Acid on the Removal of Cd, Ni, Pb and Cu from Artificially Contaminated Soil by Althaea rosea Cavan. Int J Phytoremediation. 2015;17(1-6):568-574. doi:10.1080/15226514.2014.935285 2) Khan WU, Yasin NA, Ahmad SR, Ali A, Ahmed S, Ahmad A. Role of Ni-tolerant Bacillus spp. and Althea rosea L. in the phytoremediation of Ni-contaminated soils. Int J Phytoremediation. 2017;19(5):470-477. doi:10.1080/15226514.2016.1244167

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Alyssum bertolonii	Alyssum	Heavy Metals	Ni	Not available
Alyssum bracteatum	Alyssum	Heavy Metals	Ni	Not available
Alyssum lesbiacum	Alyssum	Heavy Metals	Ni	Not available
Alyssum murale	Yellowtuft	Heavy Metals	Ni	Herbaceous
Alyssum murale	Yellowtuft	Heavy Metals	Ni	Herbaceous
Alyssum wulfenianum	Alpine Alyssum	Heavy Metals	Ni	Herbaceous
Amaranthus hypochondriacus	Amaranth Prince-of-Wales Feather	Heavy Metals	Cd	Herbaceous
Amaranthus hypochondriacus L.	Amaranth	Heavy Metals	Cd	Herbaceous
Amaranthus retroflexus	Redroot Pigweed	Radionuclides	Cs	Herbaceous
Amaranthus retroflexus	Redroot Amaranth	Heavy Metals	Cd, Cs, Ni, Zn	Herbaceous
Ambrosia artemisiifolia L.	Common ragweed	Heavy Metals	Pb	Herbaceous
Amorpha fruticosa	Indigo Bush	Heavy Metals	Pb	Shrub
Amorpha fruticosa Linn.	Desert False Indigo	Heavy Metals	Zn, Pb ,Cu	
Andropogon geradi Andropogon geradii var. Pawne	Big Bluestem	Pesticides	Chlorpyrifos Chloro-thalonil Pendimethalin Propiconazole Altrazine Pendimethalin	Herbaceous
Andropogon geradii	Big Bluestem	Heavy Metals	Anthracene, As, Atrazine, Cu, Polychlorinated Biphe-nyl (PCB)	Herbaceous
Andropogon gerardi	Big Blue Stem		Atrazine	Herbaceous
Andropogon gerardii	Big Bluestem	Petroleum	PAH	Herbaceous
Arabidopsis halleri		Heavy Metals	Cd, Pb, Zn	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Hyperaccumulator	Not available	Italy	Robinson et al., 1997b
Hyperaccumulator	Not available	Iran	Ghaderian et al., 2007
Hyperaccumulator	Not available	Not available	Kupper et al., 2001
Hyperaccumulator	2–5	Balkans	Bani et al., 2007 Chaney et al., 2003, 2007, 2010 Prasad, 2005
Hyperaccumulator	2–5	Balkans	Bani A, Echevarria G, Sulçe S, Morel JL. Improving the Agronomy of Alyssum murale for Extensive Phytomining: A Five-Year Field Study. Int J Phytoremediation. 2015;17(1-6):117-127. doi:10.1080/15226514.2013.862204
Accumulator			1) Reeves, R.D. and R.R. Brooks, 1983. Hyperaccumulation of Pb and Zn by two metallo-phytes from a mining area of central Europe. EnvFe. Pollut. A Ecol. Biol., 31: 277-287. http://scialert.net/fulltext/?doi=jest.2011.118.138&org=11#571365_ja
Accumulator	Not available	Mexico	Li et al., 2013
Accumulator			(Phyto Textbook) Ci, N., Li, Z., Fu., Q., Zhuang, P., Guo, B., and Li, H. 2013. Agricultural technologies for enhancing the phytoremediation of Cd-contaminated soil by Amaranthus hypochondriacus L. Water, Air, and Soil Pollution 224 (9), pp. 1-8.
Extraction	3–10	North America	Negri and Hinchman, 2000 from Lasat et al., 1997
N/A	3–10	North America	1) McCutcheon & Schnoor 2003, Phytoremediation. New Jersey, John Wiley & Sons pg 19
Hyperaccumulator			1) McCutcheon, S.C.; Schnoor, J.L., Phytoremediation: Transformation and Control of Con-taminants, A Wiley-Interscience Series of Texts and Monographs, Hoboken, NJ: John Wiley, pp. 59
Accumulator of Pb			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Accumulator			Shi X, Chen YT, Wang SF, et al. Phytoremediation potential of transplanted bare-root seedlings of trees for Pb/Zn and Cu mine tailings. Int J Phytoremediation. 2016;18(11):1155-1163. doi:10.1080/15226514.2016.1189399
Degradation or hydraulic control	4–9	North America	Henderson et al., 2006 Smith et al., 2008
Accumulator, hyperaccumu-lator	4–9	North America	1) The University of Texas. http://wildflower.org/explore/
			Khrunyk Y, Schiewer S, Carstens KL, Hu D, Coats JR. Uptake of C14-atrazine by prairie grasses in a phytoremediation setting. Int J Phytoremediation. 2017;19(2):104-112. doi:10.1080/15226514.2016.1193465
Degradation	4–9	North America	Aprill and Sims, 1990 Balcom and Crowley, 2009 Cook and Hesterberg, 2012 Euliss, 2004 Olson et al., 2007 Rugh, 2006
Hyperaccumulator			Tlustoš P, B?endová K, Száková J, Najmanová J, Koubová K. The long-term variation of Cd and Zn hyperaccumulation by Noccaea spp and Arabidopsis halleri plants in both pot and field conditions. Int J Phytoremediation. 2016;18(2):110-115. doi:10.1080/15226514.2014.981243

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Arabidopsis halleri (Cardaminopsis halleri)	Rockcress	Heavy Metals	Cd, Zn	Herbaceous
Arabidopsis thaliana	Arabidopsis (transgenic)	Explosives	RDX	Herbaceous
Arabis flagellosa	Rock Cress	Heavy Metals	Cd	Herbaceous
Arabis gemmifera	Rockcress	Heavy Metals	Cd	Herbaceous
Arbutus unedo 'compacta'	Compact Strawberry Bush	Petroleum	Unspecified	Shrub
Arenaria humifusa Wahlenb.	Low Sandwort	Heavy Metals	Ni	Not available
Arenaria rubella	Sandwort	Heavy Metals	Ni	Herbaceous
Arrhenatherum elatius	False Oat Grass	Heavy Metals	Ni, Cu, Cd, Co, Mn, Cr, Zn	Herbaceous
Arrhenatherum elatius	Tall Oat Grass	Heavy Metals	Ni, Cu, Cd, Co, Mn, Pb, Cr Zn	Herbaceous
Artemisia frigida	Frindged Sage	Heavy Metals	Cu, Hydrocarbons	
Arundo donax	Giant Reed	Heavy Metals	Ni	
Aspilia africana	Haemorrhage plant	Petroleum	Petroleum hydrocarbons	
Astragalus bisulcatus	Two-Grooved Milkvetch	Heavy Metals	Se	Herbaceous
Astragalus grayi	Gray's Milkvetch	Heavy Metals	Se	Herbaceous
Astragalus osterhouti	Osterhout Milkvetch	Heavy Metals	Se	Herbaceous
Astragalus pattersonii	Patterson's Milkvetch	Heavy Metals	Se	Herbaceous
Astragalus pectinatus	Narrowleaf Milkvetch	Heavy Metals	Se	Herbaceous
Astragalus racemosus	Cream Milkvetch	Heavy Metals	Se	Herbaceous
Athyrium yokoscense	Hebino-negoza Fern	Heavy Metals	Cd, Cu	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Hyperaccumulator	6+	Europe	Baker, 2000 Baker and Brooks, 1989 Banasova and Horak, 2008 Reeves, 2006 Zhao et al., 2006
Degradation	1+	Europe, Asia	Rylott et al., 2011 Strand et al., 2009
Accumulator	Not available	Asia	Chen et al., 2009
Accumulator	Not available	Japan	Kubota et al., 2003
Tolerance	7–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Hyperaccumulator	Not available	Eastern North America, Northern Canada, Europe	Phytorem Database Rune and Westerbergh, 1992
Hyperaccumulator	4	Western USA	Kruckeberg et al., 1993
Accumulator	4–9	Europe	Lu et al., 2013
Accumulator			(Phyto Textbook) Lu, Y., Li, X., He, M., and Zeng, F. 2013. Behavior of native species Arrhenatherum elatius (Poaceae) and Sonchus transcaspicus (Asteraceae) exposed to a heavy metal polluted field: plant metal concentration phytotoxicity and detoxification responses. International Journal of Phytoremediation 15, pp. 924-937.
N/A			1) Robison, Diana. â€œPHYTOREMEDIATION OF HYDROCARBON-CONTAMINATED SOIL. â€ University of Saskatchewan, 2003. Web. 18 Feb2011. .
Accumulator			Galal TM, Shehata HS. Growth and nutrients accumulation potentials of giant reed (Arundo donax L.) in different habitats in Egypt. Int J Phytoremediation. 2016;18(12):1221-1230. do i:10.1080/15226514.2016.1193470 - Atma W, Larouci M, Meddah B, Benabdeli K, Sonnet P. Evaluation of the phytoremediation potential of Arundo donax L. for Ni-contaminated soil. Int J Phytoremediation. 2017;19(4):377-386. doi:10.1080/15226514.2016.1225291
Accumulator/Tolerant			Anyasi RO, Atagana HI. Profiling of plants at petroleum contaminated site for phytoremediation. Int J Phytoremediation. 2018;20(4):352-361. doi:10.1080/15226514.2017.1393386
Hyperaccumulator	2–7	Western North America	Baker and Reeves, 2000 Byers, 1935 Byers, 1936 Lakin and Byers, 1948 Rosenfeld and Beath, 1964 Van der Ent et al., 2013
Hyperaccumulator	Not available	Western North America	Baker and Reeves, 2000 Byers, 1935
Hyperaccumulator	Not available	Western North America	Baker and Reeves, 2000 Rosenfeld and Beath, 1964
Hyperaccumulator	Not available	Western North America	Baker and Reeves, 2000
Hyperaccumulator	2–6	Western North America	Baker and Reeves, 2000 Rosenfeld and Beath, 1964
Hyperaccumulator	3–10	Western North America	Baker and Reeves, 2000 Byers, 1936 Chaney et al., 2010 Knight and Beath, 1937 Moxon et al., 1950 Rosenfeld and Beath, 1964 White et al., 2007
Accumulator	7	Japan	Chen et al., 2009

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Athyrium yokoscense	Fern	Heavy Metals	Cd, Cu, Pb	Herbaceous
Atriplex confertifolia	Shadscale Saltbush	Heavy Metals	Se	Shrub
Atriplex halimus	Mediterranean saltbush	Heavy Metals	Cd, Pb	Shrub
Atriplex hortensis	Garden Orach		Polychlorinated Biphenyl (PCB)	
Atriplex hortensis var. purpurea	Golden Orache	Heavy Metals	Zn	Herbaceous
Atriplex lentiformis	Big Saltbush	Other	Salinity	Shrub
Atriplex rosea	Saltbush	Heavy Metals	Cu, Pb, Ni, Zn	Shrub
Atriplex semibaccata	Australian saltbush	Heavy Metals	Cu, Cd	Shrub
Avena nuda	Grass/Oat	Heavy Metals	Sr	Herbaceous
Avena sativa	Oat	Petroleum	TPH	Herbaceous
Avena sativa	Oat	Heavy Metals	Sr	Herbaceous
Averrhoa carambola	Star Fruit	Heavy Metals	Cd	Tree
Avicennia marina	Grey mangrove	Heavy Metals	Cd	
Axonopus compressus	Carpet Grass	Petroleum	TPH	Herbaceous
Axonopus compressus	Carpet Grass, Blanket Grass	Heavy Metals	Pb, Zn, Cu, Cd, Petroleum hydrocarbon	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator, Hyperaccumu-lator			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pd. fpg 898
Hyperaccumulator	6–10	Western North America	Baker and Reeves, 2000 Rosenfeld and Beath, 1964
Tolerant			El-Bakatoushi R, Alframawy AM, Tammam A, Youssef D, El-Sadek L. Molecular and Physio-logical Mechanisms of Heavy Metal Tolerance in Atriplex halimus. Int J Phytoremediation. 2015;17(9):789-800. doi:10.1080/15226514.2014.964844
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Accumulator	11	Europe, Asia	Kachout et al., 2012
Hyperaccumulator			Devi S, Nandwal AS, Angrish R, Arya SS, Kumar N, Sharma SK. Phytoremediation potential of some halophytic species for soil salinity. Int J Phytoremediation. 2016;18(7):693-696. doi:10.1080/15226514.2015.1131229
Accumulator			(Phyto Textbook) Kachout SS, Mansoura AB, Mechergui R, Leclerc JC, Rejeb MN, Ouerghi Z. Accumulation of Cu, Pb, Ni and Zn in the halophyte plant Atriplex grown on polluted soil. J Sci Food Agric. 2012;92(2):336?342. doi:10.1002/jsfa.4583
Hyperaccumulator			Baycu G, Tolunay D, Ozden H, et al. An Abandoned Cu Mining Site in Cyprus and Assessment of Metal Concentrations in Plants and Soil. Int J Phytoremediation. 2015;17(7):622-631. doi:10.1080/15226514.2014.922929
Accumulator			Qi L, Qin X, Li FM, et al. Uptake and distribution of stable Sr in 26 cultivars of three crop species: oats, wheat, and barley for their potential use in phytoremediation. Int J Phytore-mediation. 2015;17(1-6):264-271. doi:10.1080/15226514.2014.898016
Degradation	5–10	Europe	Cook and Hesterberg, 2012 Muratova et al., 2008
Accumulator	5–10	Europe	1) U.S EnvFemental Protection Agency (EPA). Phytoremediation field studies database for chlorinated solvents, pesticides, explosives, and metals. http://www.afcee.af.mil/shared/media/document/AFD-071130-018Journal of Experimental Botany 2006 57(12):2955-2965; doi:10.1093/jxb/erl056 2) Qi L, Qin X, Li FM, et al. Uptake and distribution of stable Sr in 26 cultivars of three crop species: oats, wheat, and barley for their potential use in phytoremediation. Int J Phytoremediation. 2015;17(1-6):264-271. doi:10.1080/15226514.2014.898016
Accumulator	9–11	Southeast Asia	Li et al., 2007
Tolerant			Jian L, Chongling Y, Daolin D, Haoliang L, Jingchun L. Accumulation and speciation of Cd in Avicennia marina tissues. Int J Phytoremediation. 2017;19(11):1000-1006. doi:10.1080/15226514.2017.1303817
Degradation	7–10	North America, South America	Efe and Okpali, 2012
Accumulator	7–10	North America, South America	(Phyto Textbook) Efe, S.I., and Okpali, A.E. 2012. Management of petroleum impacted soil with phytoremediation and soil amendments in Expan Delta State, Nigeria. Journal of En-vFemental Protection 3, pp. 386-393. - Chamba I, Gazquez MJ, Selvaraj T, Calva J, Toledo JJ, Armijos C. Selection of a suitable plant for phytoremediation in mining artisanal zones. Int J Phytoremediation. 2016;18(9):853-860. doi:10.1080/15226514.2016.1156638

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Azolla filiculoides	Water Fern		Methyl violet 2B	Herbaceous
Bacopa monnieri	Smooth Water Hyssop	Heavy Metals	Cd, Cu, Pb, Cr, Hg	
Bassia scoparia	Summer Cypress Mexican Firebush	Heavy Metals	As	Shrub
Berkheya coddii	South African Aster	Heavy Metals	Ni	Not available
Beta vulgaris	Beet	Heavy Metals	As	Herbaceous
Beta vulgaris	Beet	Radionuclides	Cs	Herbaceous
Beta vulgaris var. cicla	Swiss Chard	Heavy Metals	Cd	
Betula nigra	River Birch		Bentazon, Polychlorinated Biphenyl (PCB), Trichloroethylene (TCE) and by-products, Vinyl Chloride	
Betula pendula	European White Birch	Petroleum	PAH	Tree
Betula pendula	European White Birch	Chlorinated Solvents	TCE	Tree
Betula pendula	Birch	Heavy Metals	Cd, Zn, Chlorinated Aliphatic Compounds, Trichloroethylene (TCE), heavy metals	Tree
Bidens pilosa	Beggar Ticks Spanish Needle	Heavy Metals	Cd	Herbaceous
Bornmuellera tymphaea	Bornmuellera	Heavy Metals	Ni	Herbaceous
Bougainvillea spectabilis Wiild	Great Bougainvillea	Heavy Metals	Cd	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Hyperaccumulator of Cr, Accumulator, Tolerant			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plan_ospecies_ophyto.pd http://www.flickr.com/photos/fjbn/364307000 Azollaceae - Azolla filiculoides Lam. by Fundacin Jardin Botinico Nacional de Viia del, on Flickr http://farm3.staticflickr.com/2471/3643070002_4eace4b90djpg "Azollaceae - Azolla filiculoides Lam. 3) http://www.brighthub.com/engineering/civil/articles/118344.asxx) sesak Kulen O, Memon A, ksel B. Phytoremediation of petroleum hydrocarbons by using a freshwater fern species Azolla filiculoides Lam. Int J Phytoremediation. 2016;18(5):467-476. doi:10.1080/15226514.2015.1115958 5) Kooh MRR, Lim LBL, Lim LH, Malik OA. Phytoextraction potential of water fern (Azolla pinnata) in the removal of a hazardous dye, methyl violet 2B:
Accumulator			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Potential Accumulators	Grown as annual	Spain	Gisbert et al., 2008
Hyperaccumulator	Not available	South Africa	Keeling et al., 2003 Morrey et al., 1989 Robinson et al., 1997a
Potential Accumulators	Grown as annual	Mediterranean	ITRC PHYTO 3 Speir et al., 1992
Extraction	Grown as annual	Mediterranean	Broadley and Willey, 1997 Negri and Hinchman, 2000 Willey et al., 2001
Accumulator			Broadhurst CL, Chaney RL, Davis AP, et al. Growth and Cd Phytoextraction by Swiss Chard, Maize, Rice, Noccaea caerulescens, and Alyssum murale in Ph Adjusted Biosolids Amended Soils. Int J Phytoremediation. 2015;17(1-6):25-39. doi:10.1080/15226514.2013.828015
N/A			2) Solvents in Groundwater: Pilot Study at a Superfund Sis . In: G. Wickramanayake, A. Gavaskar, B. Alleman, and V. Magar (eds.) Bioremediation and Phytoremediation of Chlorinated and Recalcitrant Compounds, p461-466. Battelle Press, Columbus, Ohio.; Ferro, A., Kennedy, J., Kjelgren, R., Rieder, J., and S. Perrin. 1999."Toxicity Assessment of Volatile Organic Compounds in Poplar Trees" . International Journal of Phytoremediation. 1(19-17
Degradation	3–6	Europe	Cook and Hesterberg, 2012 Rezek et al., 2009
Degradation	3–6	Europe	Lewis et al., 2013
Accumulator, Hyperaccumulator	3–6	Europe	1) McCutcheon, S.C, & Schnoor. J.L. (Eds.) (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience.Inc.- http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf 3) (Phyto Textbook) Evangelou, M.W., Robinson, B.H., Gunthardt-Goerg, M.S., and Schlin, R. 2013. Metal uptake and allocation in trees grown on contaminated land: implications for biomass production. International Journal of Phytoremediation 15 (1), pp. 77-90. 4) (Phyto Textbook) Lewis, J., Qvarfort, U. and Sjostrom, J. 2013. Betula pendula: a promising candidate for phytoremediation of TCE in northern climate, International Journal of Phytoremediation, DOI, 140528074112008. 5) (Phyto Textbook) Saebo, A., Popek, R., Nawrot, B., Hanslin, H., Gawronska, H. and Gawronski, S. 2013. Plant species differences in particulate matter accumulation on leaf surfaces. Science of the Total Envrionment 427, pp
Accumulator	Not available	North America, South America	Wei and Zhou, 2008
Hyperaccumulator	Not available	Greece	Chardot et al., 2005
Accumulator			Wang W, Zhang M, Liu J. Subcellular distribution and chemical forms of Cd in Bougainvillea spectabilis Willd. as an ornamental phytostabilizer: An integrated consideration. Int J Phytoremediation. 2018;20(11):1087-1095. doi:10.1080/15226514.2017.1365335

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Bouteloua curtipendula	Side Oats Grass	Petroleum	TPH PAH	Herbaceous
Bouteloua curtipendula	Sideoats Grama	Heavy Metals	Al, As, Cu, Pb, Mn, Zn	
Bouteloua dactyloides	Buffalo Grass	Petroleum	PAH TPH	Herbaceous
Bouteloua dactyloides	Buffalo Grass	Other	CO_2, Hydrocarbons, Polycyclic Aromatic Hydrocarbon (PAH)	Herbaceous
Bouteloua gracilis	Blue Grama	Petroleum	PAH	Herbaceous
Bouteloua gracilis	Blue Gamma Grass	Other	CO_2	Herbaceous
Brachiaria brizantha	Signal grass	Heavy Metals	Zn	Herbaceous
Brachiaria decumbens	Signal Grass	Petroleum	TPH	Herbaceous
Brachiaria mutica	Paragrass	Heavy Metals	Cr	Herbaceous
Brachiaria serrata	Velvet Signal Grass	Petroleum	TPH	Herbaceous
Brassica campestris	Mustard	Pesticides	Endosulfan	Herbaceous
Brassica campestris Linn.	Mustard	Pesticides	Endosulfan (cyclodiene insecticide)	
Brassica carinata	Ethiopian Mustard Abyssinian Cabbage	Heavy Metals	Ni	Herbaceous
Brassica juncea	Indian Mustard	Petroleum	PAH	Herbaceous
Brassica juncea	Indian Mustard	Heavy Metals	As	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation	3–9	North America, South America	Aprill and Sims, 1990 Cook and Hesterberg, 2012
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf 2) ITRC â€" Phytotechnology Technical and Regulatory Guidance and Decision Trees. Revised by The Interstate Technology & Regulatory Council Phytotechnologies Team February 2009 CO2
Degradation	3–9	North America	McCutcheon and Schnoor, 2003 Qiu et al., 1997
Accumuluator			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. 2) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 3) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf 4) USDA NRCS Plant Materials Center, Manhattan, Kansas & Kansas State University, Forestry Researchhttp://plants.usda.gov/factsheet/pdf/fs_sani.pdf
Degradation	3–9	North America	Aprill and Sims, 1990 Cook and Hesterberg, 2012
N/A			1) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 2) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Accumulator, Tolerant			1) Silva EB, Fonseca FG, Alleoni LR, Nascimento SS, Grazziotti PH, Nardis BO. Availability and toxicity of Cd to forage grasses grown in contaminated soil. Int J Phytoremediation. 2016;18(9):847-852. doi:10.1080/15226514.2016.1146225 2) Nardis BO, Silva EB, Grazziotti PH, Alleoni LRF, Melo LCA, Farnezi MMM. Availability and Zn accumulation in forage grasses grown in contaminated soil. Int J Phytoremediation. 2018;20(3):205-213. doi:10.1080/15226514.2017.1365347
Degradation	Not available	Africa	Cook and Hesterberg, 2012 Gaskin and Bentham, 2010
Hyperaccumulator			(Phyto Textbook) Mohanty, M., and Patra, H. K. 2012. Phytoremediation Potential of Paragrass— An In Situ Approach for Cr Contaminated Soil. International Journal of Phytoremediation 14 (8), pp. 798-805.
Degradation	Not available	Africa	Maila and Randima, 2005
Degradation or hydraulic control	7+	Europe	Mukherjee and Kumar, 2012
Accumulator			(Phyto Textbook) Mukherjee, I., and Kumar, A. 2012. Phytoextraction of endosulfan a remediation technique. Bulletin of EnvFemental Contamination and Toxicology 88 (2), pp. 250-254.
Accumulator	Not available	Africa	Purakayastha et al., 2008
Degradation	Grown as annual	Asia, Europe, Africa	Roy et al., 2005
Potential Accumulators	Grown as annual	Central Asia	Anjum et al., 2014

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Brassica juncea	Indian Mustard	Heavy Metals	Ni	Herbaceous
Brassica juncea Brassica juncea cv., 182921 Brassica juncea cv. Pusa Jia Kisan Brassica juncea cv., 426308	Indian Mustard	Heavy Metals	Cu, Cd, Cr(VI), Ni, Zn	Herbaceous
Brassica juncea Brassica juncea cv., 426308	Indian Mustard	Radionuclides	137Cs, 238U	Herbaceous
Brassica napus	Canola	Pesticides	Chlorpyrifos	Herbaceous
Brassica napus	Rapeseed	Heavy Metals	Cd, Cu, Zn	Herbaceous
Brassica oleracea var. capitata.	Cabbage	Heavy Metals	Cs	
Brassica rapa	Turnip	Radionuclides	99Tc, 137Cs	Herbaceous
Brickellia sp.	Brickellbush	Heavy Metals	Zn	Shrub
Bromus inermis	Smooth Brome	Petroleum	TPH	Herbaceous
Broussonetia papyrifera	Paper Mulberry	Heavy Metals	Pb	
Bryophyllum pinnatum	Cathedral bells	Petroleum	Petroleum hydrocarbons	
Bulbine frutescens	Snake Flower	Petroleum	Unspecified	Herbaceous
Cabomba aquatica	Fanwort	Pesticides	Cu sulfate Dimethomorph Flazasulfron	Wetland
Cajanus cajan	Pigeon pea	Heavy Metals	Cr, Pb	
Cakile maritima	European Sea Rocket	Radionuclides	Th, U	Herbaceous
Calendula algeriensis Boiss and Reuter		Heavy Metals	Pb, Zn, Cu ,Cd	
Calendula officinalis L	Pot Marigold, Ruddles	Heavy Metals	Cd, Pb	
Calluna vulgaris	Common Heather	Radionuclides	137Cs	Herbaceous
Caltropis gigantea	Giant Milky Weed	Radionuclides	Sr, Cs	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Hyperaccumulator	Grown as annual	Asia Europe, Africa	Saraswat and Rai, 2009
Accumulator	2–11	Eurasia	Bauddh and Singh, 2012 Blaylock et al., 1997 Bluskov et al., 2005 ITRC PHYTO 3 Kumar et al., 1995 Lai et al., 2008
Extraction	Grown as annual	Asia, Europe, Africa	Dushenkov et al., 1997b ITRC PHYTO 3 Vasudev et al., 1996
Degradation or hydraulic control	7+	Mediterranean	White and Newman, 2007
Accumulator	2–11	Eurasia	Thewys et al., 2010 Van Slycken et al., 2013 Witters et al., 2012
N/A			1) Phytoremediation of RadioÂ¬nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm
Extraction	Grown as annual	Europe	Bell et al., 1988 ITRC PHYTO 3
Accumulator			(Phyto Textbook) Cortes-Jimenez, E., Mugica-Alvarez, V., Gonzalez-Chavez, M., Carril-lo-Gonzalez, R., Gordillo, M., and Mier, M. 2013. Natural revegetation of alkaline tailing heaps at Taxco, Guerrero, Mexico. International Journal of Phytoremediatio15 (2), pp. 127-141.
Degradation	3–9	Europe, Asia	Cook and Hesterberg, 2012 Muratova et al., 2008
Accumulator/Tolerant			Kang W, Bao J, Zheng J, Xu F, Wang L. Phytoremediation of heavy metal contaminated soil potential by woody plants on Tonglushan ancient Cu spoil heap in China. Int J Phytoreme-diation. 2018;20(1):1-7. doi:10.1080/15226514.2014.950412
Accumulator/Tolerant			Anyasi RO, Atagana HI. Profiling of plants at petroleum contaminated site for phytoremedi-ation. Int J Phytoremediation. 2018;20(4):352-361. doi:10.1080/15226514.2017.1393386
Tolerance	8–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Degradation or hydraulic control	9+	South America	Olette et al., 2008
Accumulator			Jerez Ch JA, Romero RM. Evaluation of Cajanus cajan (pigeon pea) for phytoremediation of landfill leachate containing Cr and Pb. Int J Phytoremediation. 2016;18(11):1122-1127. doi:1 0.1080/15226514.2016.1186592
Extraction	6–10	Europe	Hegazy and Emam, 2011
Accumulator			Midhat L, Ouazzani N, Esshaimi M, Ouhammou A, Mandi L. Assessment of heavy metals ac-cumulation by spontaneous vegetation: Screening for new accumulator plant species grown in Kettara mine-Marrakech, Southern Morocco. Int J Phytoremediation. 2017;19(2):191-198. doi:10.1080/15226514.2016.1207604
Accumulator			Mani D, Kumar C, Patel NK. Hyperaccumulator oilcake manure as an alternative for che-late-induced phytoremediation of heavy metals contaminated alluvial soils. Int J Phytore-mediation. 2015;17(1-6):256-263. doi:10.1080/15226514.2014.883497
Extraction	4–10	Europe	Bunzl and Kracke, 1984 ITRC PHYTO 3
Extraction	10–11	Asia	Eapen et al., 2006

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Canavalia ensiformis L.	Jack Bean	Heavy Metals	Cd	
Canna × generalis	Canna	Petroleum	BTEX	Herbaceous
Cannabis sativa	Hemp	Heavy Metals	Cd	
Carduus pycnocephalus L. subsp. pycnocephalus	Italian Thistle	Heavy Metals	Cd, Cr, Cu, Ni, Pb, Zn	Herbaceous
Carex aquatica	Sedge	POP	PCB	Herbaceous
Carex cephalophora	Ovalhead Sedge	Petroleum	PAH	Herbaceous
Carex gracilis	Slim Sedge	Explosives	TNT	Herbaceous
Carex lyngbyei	Lyngbye's Sedge	Heavy Metals	Cd, Pb	
Carex nigra	Black Sedge	Radionuclides	137Cs	Herbaceous
Carex praegracilis	Clustered Field Sedge		Trichloroethylene (TCE) and by-products	
Carex stricta	Sedge	Petroleum	TPH	Herbaceous
Carex vulpinoidea	Fox Sedge	Heavy Metals	Cd, Cu, Pb	
Cassia corymbosa	Senna	Petroleum	Unspecified	Shrub
Castilleja chromosa	Indian Paintbrush	Heavy Metals	Se	Herbaceous
Catharanthus roseus	Madagascar Periwinkle	Explosives	HMX RDX TNT	Herbaceous
Catharanthus roseus L. w/ P. fluorescens and B. subtilis	Madasgascar Periwinkle	Heavy Metals	Cu, Pb	
Ceder la fissilis		Heavy Metals	Zn, Cd, Cu, Pd	
Celosia argentea Linn.	Plumed Cockscomb	Heavy Metals	Mc, Cd	
Celtis occidentalis	Hackberry	Petroleum	BTEX TPH PAH	Tree

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			Ariana Carramaschi Francato Zancheta, Cleide Aparecida De Abreu, Fernando César Bachie-gaZambrosi, Norma de Magalhães Erismann & Ana Maria Magalhães Andrade Lagôa (2015) Cd Accumulationby Jack-Bean and Sorghum in Hydroponic Culture, International Journal of Phytoremediation, 17:3, 298-303, DOI:10.1080/15226514.2014.883492 (1) (PDF) Cd Accumulation by Jack-Bean and Sorghum in Hydroponic Culture. Available from: https://www.researchgate.net/publication/268336638_Cd_Accumulation_by_Jack-Bean_and_Sorghum_in_Hydroponic_Culture [accessed Jun 25 2020].
Degradation	8–12	Central and South America, Southern USA	Boonsaner et al., 2011
Accumulator			Ahmad A, Hadi F, Ali N. Effective Phytoextraction of Cd (Cd) with Increasing Concentration of Total Phenolics and Free Proline in Cannabis sativa (L) Plant Under Various Treatments of Fertilizers, Plant Growth Regulators and Na Salt. Int J Phytoremediation. 2015;17(1-6):56-65. doi:10.1080/15226514.2013.828018
Excluder	7+	Southern Europe	Perrino et al., 2012 Perrino et al., 2013
Extraction	3+	North America	Smith et al., 2007
Degradation	3–8	Eastern USA	Cook and Hesterberg, 2012 Euliss, 2004
Degradation	3–7	North America	Nepovim et al., 2005 Vanek et al., 2006.
N/A			1) Gallagher, J.L and H.V. Kibby, 1980. Marsh plants as vectors in trace metal transport in Oregon tidal marshes. American Journal of Botany, 67: 1069-1074
Extraction	4–8	Europe, Eastern North America	ITRC PHYTO 3 Olsen, 1994
N/A			1) Jordahl, J., R. Tossell, M. Barackman and G. Vogt (2003) Phytoremediation for Hydraulic Control and Remediation: Beale 2) Air Force Base and Koppel Stockton Terminal. Abstracts from US EPA International Applied Phytotechnologies Workshop March 3-5, 2003 Chicago, I
Degradation	5–8	North America	Euliss et al., 2008
Accumulator			1) http://www.arkive.org/true-fox-sedge/carex-vulpina/image-A2883.html
Tolerance	8–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Hyperaccumulator	4–9	Western North America	Baker and Reeves, 2000 Rosenfeld and Beath, 1964
Degradation	10–11	Madagascar	Bhadra et al., 2001 Hughes et al., 1997 Thompson et al., 1999
Tolerant			Khan WU, Ahmad SR, Yasin NA, Ali A, Ahmad A. Effect of Pseudomonas fluorescens RB4 and Bacillus subtilis 189 on the phytoremediation potential of Catharanthus roseus (L.) in Cu and Pb-contaminated soils. Int J Phytoremediation. 2017;19(6):514-521. doi:10.1080/15226514.2016.1254154
Tolerant			Meyer ST, Castro SR, Fernandes MM, Soares AC, de Souza Freitas GA, Ribeiro E. Heavy-metal-contaminated industrial soil: Uptake assessment in native plant species from Brazilian Cerrado. Int J Phytoremediation. 2016;18(8):832-838. doi:10.1080/15226514.2016.1146224
Hyperaccumulator			Liu J, Mo L, Zhang X, Yao S, Wang Y. Simultaneous hyperaccumulation of Cd and Mn in Celosia argentea Linn. Int J Phytoremediation. 2018;20(11):1106-1112. doi:10.1080/15226514.2017.1365341
Degradation	2–9	North America	Cook and Hesterberg, 2012 Fagiolo and Ferro, 2004 Kulakow, 2006b

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Centella asiatica	Indian pennywort	Heavy Metals	Fe	
Cerastium arvense	Field Chickweed	Heavy Metals	Cd	Herbaceous
Cerastium fontanum	Chickweed	Radionuclides	134Cs	Herbaceous
Ceratophyllum demersum	Coontail	Pesticides	Metolachor	Herbaceous
Ceratophylum demersum	Hornwart	Explosives	RDX	Wetland
Cercis canadansis	Eastern Redbud	Petroleum	PAH	Herbaceous
Cercis canadensis	Eastern Redbud	Petroleum	Unspecified	Tree
Chamaedorea seifrizii	Bamboo Palm		Benzene, Formaldehyde, Toluene, Xylene	
Chara	Stonewart	Explosives	RDX	Wetland
Chelidonium majus var. asiaticum	Nipplewort	Heavy Metals	As	Herbaceous
Chelidonium majus var. asiaticum	Celandine	Heavy Metals	As	Herbaceous
Chenopodium ambrosioides L.	Mexican tea		Mn	
Chenopodium quinoa	Quinoa	Radionuclides	Cs	Herbaceous
Chicorium intybus var. foliosum	Chicory	Heavy Metals	Ni, Cd	Herbaceous
Chloris barbata	Swollen Fingergrass	Petroleum	Petroleum hydrocarbons	Herbaceous
Chlorophytum comosum	Spider Plant	Other	Carbon, Carbon Monoxide, Formaldehyde, Toluene, Xylene	
Christella dentata	Binung	Heavy Metals	As	
Chromolaena odorata	Siam weed	Heavy Metals	Cd, Total petroleum hydrocarbons, Pb, Petroleum hydrocarbons,	Herbaceous
Chromolaena odoratum		Heavy Metals	Cd	Shrub
Chrysanthemum leucanthemum	Oxe-Eye Daisy	POP	PCB	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Hyperaccumulator			Bhat IU, Mauris EN, Khanam Z. Phytoremediation of Fe from red soil of tropical region by using Centella asiatica. Int J Phytoremediation. 2016;18(9):918-923. doi:10.1080/1522651 4.2016.1156637
Accumulator			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Extraction	4+	Europe, Asia	ITRC PHYTO 3 Salt et al., 1992
Degradation or hydraulic control	4–10	North America	ITRC PHYTO 3 Rice et al., 1996b
Degradation	5–11	Worldwide	Kiker and Larson, 2001
Degradation	4–9	North America	Ferro et al., 1999
Tolerance	4–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
N/A			1) Wolverton, B.C. (1996) How to Grow Fresh Air. New York: Penguin Books. 2) B. C. Wolverton and J.D. Wolverton. "Plants and Soil Microorganisms: Removal of Formaldehyde, Xylene, Ammonia From the Indoor EnvFement"
Degradation	varies	varies	Kiker and Larson, 2001
Potential Accumulators	5–9	Europe, Asia	Zhang et al., 2013
Excluder	4–8	Europe, Western Asia	Zhang et al., 2013
Tolerant			Xue S, Zhu F, Wu C, Lei J, Hartley W, Pan W. Effects of Mn on the microstructures of Chenopodium ambrosioides L., A Mn tolerant plant. Int J Phytoremediation. 2016;18(7):710-719. do i:10.1080/15226514.2015.1131233
Extraction	8–10	South America	Negri and Hinchman, 2000 from Arthur, 1982
Accumulator	4–11	Mediterranean	ITRC PHYTO 3 Martin et al., 1996
Accumulator/Tolerant			Anyasi RO, Atagana HI. Profiling of plants at petroleum contaminated site for phytoremediation. Int J Phytoremediation. 2018;20(4):352-361. doi:10.1080/15226514.2017.1393386
N/A			1) Plants "Clean" Air Inside Our Homes (kilde NASA) 3) Wolverton, B.C. (1996) How to Grow Fresh Air. New York: Penguin Books. 4) B. C. Wolverton and J.D. Wolverton. "Plants and Soil Microorganisms: Removal of Formaldehyde, Xylene, Ammonia From the Indoor EnvFement". Retrieved 2011-08-27.
Accumulator			Raj A, Jamil S, Srivastava PK, Tripathi RD, Sharma YK, Singh N. Feasibility Study of Phragmites karka and Christella dentata Grown in West Bengal as As Accumulator. Int J Phytoremediation. 2015;17(9):869-878. doi:10.1080/15226514.2014.964845
Accumulator			1) Jampasri K, Pokethitiyook P, Kruatrachue M, Ounjai P, Kumsopa A. Phytoremediation of fuel oil and Pb co-contaminated soil by Chromolaena odorata in association with Micrococcus luteus. Int J Phytoremediation. 2016;18(10):994-1001. doi:10.1080/15226514.2016.118 3568
Accumulator	9–11	Thailand	Phaenark et al., 2009, 2011
Extraction	5–6	Europe	Ficko et al., 2010 Ficko et al., 2011

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Chrysanthemum x morifolium	Chrysanthemum		Benzene, Carbon Monoxide, Formaldehyde, Toluene, Trichloroethylene (TCE) and by-products, Xylene	
Chrysopogon zizanioides	Vetiver Grass	Petroleum	PAH	Herbaceous
Chrysopogon zizanioides	Vetiver Grass	Radionuclides	137Cs, 90Sr	Herbaceous
Cicer arietinum	White Chickpea	Explosives	TNT	Herbaceous
Cicer arietinum	Chick pea	Heavy Metals	Zn, Cu, Cd	
Cichorium intybus	Chicory	Heavy Metals	Cd	
Cinnamomum camphora	Camphor Tree	Heavy Metals	Cd	
Cistus × purpureus	Purple Rock Rose	Petroleum	Unspecified	Shrub
Claytonia perfoliata	Miner's Lettuce		Cd	
Clytostoma callistegioides	Lavender Trumpet Vine	Petroleum	Unspecified	Vine
Cocos nucifera	Coconut Palm	Heavy Metals	Cs	
Colocasia esculanta	Taro	Heavy Metals	As	Herbaceous
Colocasia esculenta	Taro	Heavy Metals	Cd, Zn	
Conocarpus erectus	Buttonwood	Heavy Metals	As	
Conocarpus lancifolius	Axlewood	Petroleum	TPH	Tree
Convolvulus tricolor	Dwarf morning glory	Heavy Metals	Pb, Ni	
Conyza bonariensis		Heavy Metals	Fe, Pb, Mn	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator of Benzene, Trichloroethylene, and Formaldehyde			1) http://www.colostate.edu/Depts/CoopExt/4DMG/Plants/clean.htm 2) Wolverton, B.C. (1996) How to Grow Fresh Air. New York: Penguin Books. 3) B. C. Wolverton and J.D. Wolverton. "Plants and Soil Microorganisms: Removal of Formaldehyde, Xylene, Ammonia From the Indoor EnvFement". Retrieved 2011-08-27.
Degradation	9–11	India	Cook and Hesterberg, 2012 Paquin et al., 2002
Extraction	9–11	India	Singh et al., 2008
Degradation	Grown as annual	Middle East	Adamia et al., 2006
Accumulator			Murtaza G, Javed W, Hussain A, Qadir M, Aslam M. Soil-applied Zn and Cu suppress Cd uptake and improve the performance of cereals and legumes. Int J Phytoremediation. 2017;19(2):199-206. doi:10.1080/15226514.2016.1207605
Accumulator			Xiao Y, Li Y, Che Y, Deng S, Liu M. Effects of biochar and N addition on nutrient and Cd uptake of Cichorium intybus grown in acidic soil. Int J Phytoremediation. 2018;20(4):398-404. doi:10.1080/15226514.2017.1365342
			Zeng P, Guo Z, Cao X, Xiao X, Liu Y, Shi L. Phytostabilization potential of ornamental plants grown in soil contaminated with Cd. Int J Phytoremediation. 2018;20(4):311-320. doi:10.1080/15226514.2017.1381939
Tolerance	8–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Tolerance	8–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator of Radionuclides			1) Phytoremediation of RadioÂ¬nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm
Potential Accumulators	8–10	Malaysia	Molla et al., 2010
Accumulator			Madera-Parra CA, Peña-Salamanca EJ, Peña MR, Rousseau DP, Lens PN. Phytoremediation of Landfill Leachate with Colocasia esculenta, Gynerum sagittatum and Heliconia psittacorum in Constructed Wetlands. Int J Phytoremediation. 2015;17(1-6):16-24. doi:10.1080/15226514.2013.828014, Chayapan P, Kruatrachue M, Meetam M, Pokethitiyook P. Effects of Amendments on Growth and Uptake of Cd and Zn by Wetland Plants, Typha angustifolia and Colocasia esculenta from Contaminated Sediments. Int J Phytoremediation. 2015;17(9):900-906. doi:10.1080/15226514.2014.989310 - Chayapan P, Kruatrachue M, Meetam M, Pokethitiyook P. Effects of Amendments on Growth and Uptake of Cd and Zn by Wetland Plants, Typha angustifolia and Colocasia esculenta from Contaminated Sediments. Int J Phytoremediation. 2015;17(9):900-906. doi:10.1080/15226514.2014.989310
Tolerant			Hussain S, Akram M, Abbas G, et al. As tolerance and phytoremediation potential of Conocarpus erectus L. and Populus deltoides L. Int J Phytoremediation. 2017;19(11):985-991. doi:10.1080/15226514.2017.1303815
Degradation	Not available	Africa	Cook and Hesterberg, 2012 Yateem et al., 2008
Accumulator			Valizadeh, Rezvan, and Leila Mahdavian. "Phytoremediation and Absorption Isotherms of Heavy Metal Ions ByConvolvulus Tricolor(CTC)." International Journal of Phytoremediation, vol. 18, no. 4, 2015, pp. 329–336., doi:10.1080/15226514.2015.1094449.
Accumulator			Eid EM, Shaltout KH. Bioaccumulation and translocation of heavy metals by nine native plant species grown at a sewage sludge dump site. Int J Phytoremediation. 2016;18(11):1075-1085. doi:10.1080/15226514.2016.1183578

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Conyza canadensis	Canadian Horseweed	Heavy Metals	Cd, Ni, Zn	Herbaceous
Copaifera langsdorffii	Diesel tree	Heavy Metals	Zn, Cd, Cu, Pd	
Cordia subcordata	Kou	Petroleum	TPH PAH	Tree
Coronopus didymus	Swine cress	Heavy Metals	Pb	
Cosmos bipinnatus	Garden cosmo	Petroleum	Petroleum hydrocarbons	
Cosmos sulphureus	Sulfur cosmo	Heavy Metals	Cd	
Cucumis sativus	Cucumber	Radionuclides	Co, Rb, Sr, Cs	Herbaceous
Cucumis sativus L. 'Dlikatess'	Cucumber	POP	PCDD, PCDF	Herbaceous
Cucurbita pepo	Zucchini	POP	weathered chlordane, DDX residues,	
Cucurbita pepo Cucurbita pepo L. 'Black Beauty' Cucurbita pepo L. convar. Giromontiina 'Diamant F1' Cucurbita pepo L. 'Raven' Cucurbita pepo L. 'Senator hybrid'	Zucchini	POP	p,p'-DDE (Weathered DDT) DDT HCH 2,2-bis(p-chlorophenyl)-1,1-dichloroethylene(p,p'-DDE) Chlordane PCDD PCDF	Herbaceous
Cucurbita pepo Cucurbita pepo L. 'Howden'	Pumpkin	POP	Weathered DDT PCB	Herbaceous
Cymbopogon citratus (D.C.) Stapf	Lemon Grass	Heavy Metals	Al, Zn, Pb, Cd, Cr, As, Ni	Herbaceous
Cymbopogon citrullus	Lemon-Scented Grass	Petroleum	TPH	Herbaceous
Cynodon dactylon	Bermuda Grass	Petroleum	Fluoranthene Phenan-threne Pyrene TPH PAH	Herbaceous
Cynodon dactylon	Bermuda Grass	Heavy Metals	As	Herbaceous
Cyperus alternifolius	Umbrella papyrus		Ethanolamines	
Cyperus brevifolius	Sedge rottb.	Petroleum	TPH	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator	2–11	North America	Wei et al., 2004
Tolerant			Meyer ST, Castro SR, Fernandes MM, Soares AC, de Souza Freitas GA, Ribeiro E. Heavy-metal-contaminated industrial soil: Uptake assessment in native plant species from Brazilian Cerrado. Int J Phytoremediation. 2016;18(8):832-838. doi:10.1080/15226514.2016.1146224
Degradation	Not available	Hawaii, Pacific, Africa	Tang et al., 2004
Accumulator			Sidhu GPS, Bali AS, Singh HP, Batish DR, Kohli RK. Phytoremediation of Pb by a wild, non-edible Pb accumulator Coronopus didymus (L.) Brassicaceae. Int J Phytoremediation. 2018;20(5):483-489. doi:10.1080/15226514.2017.1374331
Accumulator/Tolerant			Anyasi RO, Atagana HI. Profiling of plants at petroleum contaminated site for phytoremediation. Int J Phytoremediation. 2018;20(4):352-361. doi:10.1080/15226514.2017.1393386
Accumulator			Zhou G, Guo J, Yang J, Yang J. Effect of fertilizers on Cd accumulation and subcellular distribution of two cosmos species (Cosmos sulphureus and Cosmos bipinnata). Int J Phytoremediation. 2018;20(9):930-938. doi:10.1080/15226514.2018.1448362
Extraction	Grown as annual	India	Gouthu et al., 1997
Extraction	Grown as annual	India	Hulster et al., 1994
Accumulator			1) Final Report: EPA Grant Number r825549c045. Available at http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/5250/report/F 2) Belden, JB; Clark, BW; Phillips, TZ; Hendersen, KL; Arthur, EL; Coats, JR. 2003. Detoxification of Pesticide Residues in Soil Using Phytoremediation. ACS Symposium Series 863: Pesticide Decontamination and Detoxification, Chapter 12. Ed: JJ Gan, PC Zhu, SD Aust, AT Lemley. American Chemical Society, 2003.
Extraction	Grown as annual	North and Central America	Bogdevich and Cadocinicov, 2009 Hulster et al., 1994 Isleyen et al., 2013 Lunney et al., 2004 Mattina et al., 2004 Wang et al., 2004 White, 2001 Zeeb et al., 2006
Extraction	Grown as annual	North and Central America	Kelsey et al., 2006 Lunney et al., 2004 Wange et al., 2004 Whitfield-Aslund et al., 2007 Whitfield-Aslund et al., 2008
Tolerant			Gautam M, Pandey D, Agrawal M. Phytoremediation of metals using lemongrass (Cymbopogon citratus (D.C.) Stapf.) grown under different levels of red mud in soil amended with biowastes. Int J Phytoremediation. 2017;19(6):555-562. doi:10.1080/15226514.2016.1267701
Degradation	10–11	India	Cook and Hesterberg, 2012 Gaskin and Bentham, 2010
Degradation	7–10	Africa	Banks, 2006 Banks and Schwab, 1998 Cook and Hesterberg, 2012 Flathman and Lanza, 1999 Hutchinson et al., 2001 Kulakow, 2006e Olson and Fletcher, 2000 White et al., 2006
Potential Accumulators	7–10	Middle East	Molla et al., 2010
Accumulator			Dolphen R, Thiravetyan P. Phytodegradation of Ethanolamines by Cyperus alternifolius: Effect of Molecular Size. Int J Phytoremediation. 2015;17(7):686-692. doi:10.1080/15226514.2014.964839
Degradation	8+	Australia	Basumatary et al., 2013

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Cyperus brevifolius (Rottb.), Kyllinga brevifolia Rottb.	Shortleaf Spikesedge, Green Kyllinga, Kyllinga Weed		Petroleum hydrocarbons, Total petroleum hydrocarbons	Herbaceous
Cyperus conglomeratus		Heavy Metals	Cd, Cu, Pb, As	
Cyperus esculentus	Yellow Nutsedge	Explosives	TNT	Herbaceous
Cyperus rotundus	Purple Nutsedge	Petroleum	TPH	Herbaceous
Cyperus rotundus	Purple Nut Sedge	Heavy Metals	As	Herbaceous
Cytisus multiflorus	White Broom	Heavy Metals	As, Pb, Cu, Mn, Zn	
Cytisus scoparius	Scoth broom	Heavy Metals	Heavy Metals and Hydrocarbons	
Dactylis glomerata	Orchardgrass	Petroleum	TPH PAH	Herbaceous
Dactylis glomerata	Orchardgrass	Explosives	TNT	Herbaceous
Dactylis glomerata orchadgeus	Cat grass	Pesticides	Herbicide	Herbaceous
Daucus carota	Queen Anne's Lace	POP	PCB	Herbaceous
Dendrobium taurinum	Orchid	Organics	Acetone, Ammonia, Benzene, Chloroform, Formaldehyde, Toluene, Xylene	
Deschampsia caespitosa	Tufted Hairgrass	Heavy Metals	Cd, Cr, Cu, Pb	Herbaceous
Dichapetalum gelonoides	Gelonium Poison-Leaf	Heavy Metals	Zn	Herbaceous
Dietes irioides	Fortnight lily	Petroleum	Unspecified	Shrub
Digitalis purpurea	Common Foxglove	Heavy Metals	Cd	
Distichlis spicata	Inland Saltgrass	Heavy Metals	Cd, Cu, Pb	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumlation Quantity Accumulator			(Phyto Textbook) Basumatary, B., Saikia, R., Das, H., C., and Bordoloi, S. 2013. Field Note: Phytoremediation of Petroleum Sludge Contaminated Field Using Sedge Species, Cyperus rotundus (Linn.) and Cyperus brevifolius (Rottb.). Haask. International Journal of Phytoremediatio. 15 (9), pp. 877-888
Accumulator			Abbas ZK. Rhizospheric soil enzyme activities and phytominimg potential of Aeluropus lagopoides and Cyperus conglomeratus growing in contaminated soils at the banks of artificial lake of reclaimed wastewater. Int J Phytoremediation. 2017;19(11):1017-1022. doi:10.1080/15226514.2017.1319326
Degradation	3–9	North America, Europe, Asia	Leggett and Palazzo, 1986 Thompson et al., 1999
Degradation	8+	India	Basumatary et al., 2013 Efe and Okpali, 2012
Potential Accumulators	3–10 (invasive)	Africa	Molla et al., 2010
Accumulator			(Phyto Textbook) Gomes, P., Valente, T., Pamplona, J., Sequeira Braga, M. A., Pissarra, J., Grande Gil, J.A., and De La Torre, M.L. 2013. Metal uptake by native plants and revegetation potential of mining sulfide-rich waste-dumps. International Journal of Phytoremediation 16, pp. 1087-1103.
Accumulator			(Phyto Textbook) Macci, C., Doni, S., Peruzzi, E., Bardella, S., Filippis, G., Ceccanti, B., and Masciandaro, G. 2012. A real-scale soil phytoremediation. Biodegredation 24 (4) pp. 521-540
Degradation	3+	Europe	Cook and Hesterberg, 2012 Kulakow, 2006b
Degradation	3+	Europe	Duringer et al., 2010.
Tolerant			Buono DD, Pannacci E, Bartucca ML, Nasini L, Proietti P, Tei F. Use of two grasses for the phytoremediation of aqueous solutions polluted with terbuthylazine. Int J Phytoremediation. 2016;18(9):885-891. doi:10.1080/15226514.2016.1156633
Extraction	3–11	North America	Ficko et al., 2010
N/A			1) Wolverton, B.C. (1996) How to Grow Fresh Air. New York: Penguin Books. 2) B. C. Wolverton and J.D. Wolverton. "Plants and Soil Microorganisms: Removal of Formaldehyde, Xylene, Ammonia From the Indoor EnvFement". Retrieved 2011-08-27.
N/A			1) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 2) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Hyperaccumulator	Not available	Philippines	Reeves, 2006
Tolerance	8–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Accumulator			1) USDA NRCS Plant Materials Center, Manhattan, Kansas & Kansas State University, Forestry Researchhttp://plants.usda.gov/factsheet/pdf/fs_sani.pdf 2) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 3) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Dracaena deremensis "Warneckei"	Warneckei	Other	Benzene, Carbon Monoxide, Formaldehyde, Trichloroethylene (TCE) and by-products	
Dracaena marginata	Red-Edged Dracaena	Other	Benzene, Carbon Monoxide, Formaldehyde, Trichloroethylene (TCE) and by-products	
Dryopteris erythrosora	Autumn Fern	Heavy Metals	Cu, Pb, Hg, Zn	Herbaceous
Dryopteris filix-mas	Male Fern	Heavy Metals	As	Herbaceous
Echinochloa crus-galli	Barnyard Grass	Explosives	TNT	Herbaceous
Echinochloa crus-galli	Barnyard Grass Japanese Millet	Heavy Metals	As	Herbaceous
Echinodorus cordifolius L. Griseb	Spade-leaf Sword, Creeping Burhead		Mono, di, triethyleneglycol	
Eichhoria crassipes	Water hyacinth	Heavy Metals	Mg, Fe, Contaminants of concern (COC)	
Eichhornia crassipes	Common Water Hyacinth	Heavy Metals	Cd, Cs, Cr, Cu, Pb, Hg, Sr, U, Zn	
Elaegnus angustifolia	Russian Olive		Trichloroethylene (TCE) and by-products	
Eleusine coracana	African Millet	Petroleum	TPH	Herbaceous
Eleusine coracana	Finger millet	Heavy Metals	Cr	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
N/A			1) B.C Wolverton Ph.D -Principal investigator. NASA. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930073077_1993073077.pdf
N/A			1) B.C Wolverton Ph.D -Principal investigator. NASA. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930073077_1993073077.pdf
N/A			1) Fryer, Janet L. 2011. Microstegium vimineum. In: Fire Effects Information System, [On-line]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2011, December 7]
Potential Accumulators	4–8	America, Europe, Asia	Mahmud et al., 2008
Degradation	4–8	Europe, Asia	Lee et al., 2007
Potential Accumulators	Grown as annual	Southeast Asia	Molla et al., 2010
Accumulator			Teamkao P, Thiravetyan P. Phytoremediation of Mono-, Di-, and Triethylene Glycol by Echinodorus cordifolius L. Griseb. Int J Phytoremediation. 2015;17(1-6):93-100. doi:10.1080/15226514.2013.810579
Accumulator			1) Mercado-Borrayo BM, Cram Heydrich S, Pérez IR, Hernández Quiroz M, De León Hill CP. OrganoP and Organochlorine Pesticides Bioaccumulation by Eichhornia crassipes in Irrigation Canals in an Urban Agricultural System. Int J Phytoremediation. 2015;17(7):701-708. doi:10.1080/15226514.2014.964841 2) Romanova TE, Shuvaeva OV, Belchenko LA. Phytoextraction of trace elements by water hyacinth in contaminated area of gold mine tailing. Int J Phytoremediation. 2016;18(2):190-194. doi:10.1080/15226514.2015.1073674 3) Pandey VC. Phytoremediation efficiency of Eichhornia crassipes in fly ash pond. Int J Phytoremediation. 2016;18(5):450-452. doi:10.1080/15226514.2015.1109605 4) Hazra M, Avishek K, Pathak G. Phytoremedial Potential of Typha latifolia, Eichornia crassipes and Monochoria hastata found in Contaminated Water Bodies Across Ranchi City (India). International Journal of Phytoremediation. 2015 ;17(9):835-840. DOI: 10.1080/15226514.2014.964847.
Hyperaccumulator, Accumulator			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
N/A			1) U.S EnvFemental Protection Agency (EPA). Phytoremediation field studies database for chlorinated solvents, pesticides, explosives, and metals. http://www.afcee.af.mil/shared/media/document/AFD-071130-018.pdf
Degradation	Grown as annual	Africa	Maila and Randima, 2005
Tolerant			Padmapriya S, Murugan N, Ragavendran C, Thangabalu R, Natarajan D. Phytoremediation potential of some agricultural plants on heavy metal contaminated mine waste soils, salem district, tamilnadu. Int J Phytoremediation. 2016;18(3):288-294. doi:10.1080/15226514.2015.1085832

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Elodea canadensis	Pondweed	Heavy Metals	Atrazine, Cd, Cu, Endosulfan Sulfate, Pb, Trichloroethylene (TCE) and by-products	Herbaceous
Elodea candensis	Pondweed	Pesticides	Cu sulfate Dimethomorph Flazasulfron	Herbaceous
Elsholtzia argyi	Mint family	Heavy Metals	Cu	
Elymus canadensis	Canada Wild-Rye	Petroleum	TPH PAH	Herbaceous
Elymus hystrix	Bottlebrush Grass	Petroleum	PAH	Herbaceous
Elytrigia repens	Couch Grass	Petroleum	TPH	Herbaceous
Emilia baldwinii	Tassel Flower	Radionuclides	224Ra	Herbaceous
Eragrostis atrovirens		Petroleum	Petroleum hydrocarbons	
Eragrostis bahiensis	Bahia Lovegrass	Heavy Metals	As, Cs, Cr, Pb, Mn, Zn	Herbaceous
Erato polymnioides		Heavy Metals	Pb, Zn, Cu, Cd	
Erica andevalensis	Heather	Heavy Metals	Pb, As, Cu, Fe	Herbaceous
Erica arborea	Briar root		Mn, Pb (highest BF)	
Erigeron canadensis	Canada Fleabane	Heavy Metals	Cd, Ni	Herbaceous
Eriophorum angustifolium	Tall Cottongrass	Radionuclides	137Cs	Herbaceous
Eschscholzia californica	California Poppy	Heavy Metals	Cu	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			1) USDA NRCS Plant Materials Center, Manhattan, Kansas & Kansas State University, Forestry Researchhttp://plants.usda.gov/factsheet/pdf/fs_sani.pdf 2) Earl J.S Rook. Fens of Yodeler Creek, BWCAW. http://www.rook.org/earl/bwca/nature/aquatics/ 3) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 4) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant_species_phyto.pdf 6) Picco, Patricio, et al. As Species Uptake and Translocation in Elodea Canadensis International Journal of Phytoremediation, vol. 21, no. 7, 2019, pp. 693-698., doi:10.1080/15226514.201155658
Degradation or hydraulic control	4+	North America	Olette et al., 2008
Accumulator, Hyperaccumulator			1) Li S, Yang W, Yang T, Chen Y, Ni W. Effects of Cd Stress on Leaf Chlorophyll Fluorescence and Photosynthesis of Elsholtzia argyi--A Cd Accumulating Plant. Int J Phytoremediation. 2015;17(1-6):85-92. doi:10.1080/15226514.2013.828020 2) Guan M, Jin Z, Li J, Pan X, Wang S, Li Y. Effect of simulated climate warming on the morphological and physiological traits of Elsholtzia haichowensis in Cu contaminated soil. Int J Phytoremediation. 2016;18(4):368-377. doi:10.1080/15226514.2015.1109591
Degradation	3–9	North America	Aprill and Sims, 1990 Cook and Hesterberg, 2012
Degradation	4–9	North America	Cook and Hesterberg, 2012 Rugh, 2006
Degradation	3–9	Europe, Asia	Cook and Hesterberg, 2012 Muratova et al., 2008
Extraction	Not available	India	Hewamanna et al., 1988 ITRC PHYTO 3
Accumulator/Tolerant			Anyasi RO, Atagana HI. Profiling of plants at petroleum contaminated site for phytoremediation. Int J Phytoremediation. 2018;20(4):352-361. doi:10.1080/15226514.2017.1393386
N/A			1) Phytoremediation of RadioÂ¬nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm
Hyperaccumulator			Chamba I, Gazquez MJ, Selvaraj T, Calva J, Toledo JJ, Armijos C. Selection of a suitable plant for phytoremediation in mining artisanal zones. Int J Phytoremediation. 2016;18(9):853-860. doi:10.1080/15226514.2016.1156638
Excluder	7+	Europe	Monaci et al., 2012 Mingorance et al., 2011
Accumulator			(Phyto Textbook) Gomes, P., Valente, T., Pamplona, J., Sequeira Braga, M. A., Pissarra, J., Grande Gil, J.A., and De La Torre, M.L. 2013. Metal uptake by native plants and revegetation potential of mining sulfide-rich waste-dumps. International Journal of Phytoremediation 16, pp. 1087–1103.
Accumulator	4–8	USA	ITRC PHYTO 3 Martin et al., 1996
Extraction	4+	North America	ITRC PHYTO 3 Olsen, 1994
Excluder	9–11	Western USA	Ulrikson et al., 2012

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Eucalyptus camaldulensis	River Red Gum Eucalyptus Tree	Heavy Metals	As, Cd, Ca, Pb, Mn, Hg, Ni, Ag, Na	
Eucalyptus cladocalyx	Sugar Gum	Other	Saline soil	
Eucalyptus globulus	Southern Blue Gum	Heavy Metals	Cd, Hg	
Eucalyptus melliodora	Yellow Box, Honey Box	Other	Saline soil	
Eucalyptus polybractea	Blue-leaved Mallee	Other	Saline soil	
Eucalyptus sideroxylon "Rosea"	Red Fe Bark		Trichloroethylene (TCE) and by-products	
Eucalyptus sideroxylon 'rosea'	Red Febark	Chlorinated Solvents	TCE	Tree
Eucalyptus spp.	Eucalyptus	Petroleum	BTEX	Varies
Eucalyptus tereticornis	Eucalyptus	Radionuclides	137Cs, 90Sr	Tree
Eucalyptus urograndis	Flooded gum		Chlorobenzene, benzene	
Eugenia dysenterica	Cagaita	Heavy Metals	Zn, Cd, Cu, Pd	
Euonymus coloratus	Purple Leaf Wintercreeper	Petroleum	Unspecified	Herbaceous
Euonymus japonicas cv. Aureomar	Japanese euonymus	Heavy Metals	Cd	
Eupatorium capillifolium	Dogfennel	Heavy Metals	Cd, Ni	Herbaceous
Euphorbia milii	Crown of Thorns	Heavy Metals	Cr	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			1) Interstate Technology & Regulatory Council (ITRC). 2006. Planning and Promoting Ecological Reuse of Remediated Sites. ECO-2. Washington, D.C.: Ecological Land Reuse Team, Interstate Technology & Regulatory Council, www.itrcweb.org 3) (Phyto Textbook) Meeinkuirt, W., Pokethitiyook, P., Kruatrachue, M., Tanhan, P., and Chairyarat, R. 2012. Phytostabilization of a Pb-contaminated mine tailing by various tree species in pot and field trial experiments. International Journal of Phytoremediation 14 (9), pp. 925-938. 4) Nirola R, Megharaj M, Aryal R, Naidu R. Screening of metal uptake by plant colonizers growing on abandoned Cu mine in Kapunda, South Australia. Int J Phytoremediation. 2016;18(4):399-405. doi:10.1080/15226514.2015.1109599
Tolerant			Doronila AI, Forster MA. Performance measurement via sap flow monitoring of three eucalyptus species for mine site and dryland salinity phytoremediation. Int J Phytoremediation. 2015;17(1-6):101-108. doi:10.1080/15226514.2013.850466
Accumulator			Luo J, Qi S, Peng L, Wang J. Phytoremediation efficiency OF CD by Eucalyptus globulus transplanted from polluted and unpolluted sites. Int J Phytoremediation. 2016;18(4):308-314. doi:10.1080/15226514.2015.1094446
Tolerant			Doronila AI, Forster MA. Performance measurement via sap flow monitoring of three eucalyptus species for mine site and dryland salinity phytoremediation. Int J Phytoremediation. 2015;17(1-6):101-108. doi:10.1080/15226514.2013.850466
Tolerant			Doronila AI, Forster MA. Performance measurement via sap flow monitoring of three eucalyptus species for mine site and dryland salinity phytoremediation. Int J Phytoremediation. 2015;17(1-6):101-108. doi:10.1080/15226514.2013.850466
N/A			
Degradation	10–11	Australia	Doucette et al., 2011 Klein, 2011 Parsons, 2010
Degradation	Varies	Australia	Coltrain, 2004 Cook and Hesterberg, 2012
Extraction	9	Australia	Entry and Emmingham, 1995 ITRC PHYTO 3
Tolerant			Barcellos D, Morris LA, Nzengung V, Moura T, Mantripragada N, Thompson A. Eucalyptus urograndis and Pinus taeda enhance removal of chlorobenzene and benzene in sand culture: A greenhouse study. Int J Phytoremediation. 2016;18(10):977-984. doi:10.1080/15226514.2016.1183565
Tolerant			Meyer ST, Castro SR, Fernandes MM, Soares AC, de Souza Freitas GA, Ribeiro E. Heavy-metal-contaminated industrial soil: Uptake assessment in native plant species from Brazilian Cerrado. Int J Phytoremediation. 2016;18(8):832-838. doi:10.1080/15226514.2016.1146224
Tolerance	4–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
			Zeng P, Guo Z, Cao X, Xiao X, Liu Y, Shi L. Phytostabilization potential of ornamental plants grown in soil contaminated with Cd. Int J Phytoremediation. 2018;20(4):311-320. doi:10.1080/15226514.2017.1381939
Accumulator	4–9	Southern USA	ITRC PHYTO 3 Martin et al., 1996
Tolerant			Ramana S, Biswas AK, Singh AB, et al. Tolerance of Ornamental Succulent Plant Crown of Thorns (Euphorbia milli) to Cr and its Remediation. International Journal of Phytoremediation. 2015 ;17(1-6):363-368. DOI: 10.1080/15226514.2013.862203.

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Excoecaria agallocha	Milk Mangrove	Heavy Metals	Cd, Zn	
Festuca arundinacea	Tall Fescue	Petroleum	Anthracene Ethylene glycol Fluoranthene Phenanthrene Pyrene TPH PAH PAE	Herbaceous
Festuca arundinacea	Tall Fescue	Explosives	TNT	Herbaceous
Festuca arundinacea	Tall Fescue	POP	PCB (Delor 103 and 106)	Herbaceous
Festuca arundinacea	Tall Fescue	Heavy Metals	Zn	Herbaceous
Festuca arundinacea	Tall Fescue	Radionuclides	137Cs	Herbaceous
Festuca ovina	Sheeps fescue	Heavy Metals	Cd	
Festuca Ovina – Azay	Blue Sheep Fescue	Petroleum	Total petroleum hydrocarbons	
Festuca pratensis	Meadow Fescue	Petroleum	TPH	Herbaceous
Festuca rubra	Red Fescue	Petroleum	TPH PAH	Herbaceous
Festuca rubra	Red Fescue	Radionuclides	134Cs	Herbaceous
Festuca rubra ‘Merlin’	Red Fescue	Heavy Metals	Zn, Cu, Ni	Herbaceous
Festuca spp.	Fescue	Petroleum	TPH PAH BTEX	Herbaceous
Ficus benjamina	Weeping Fig		Formaldehyde, Toluene, Xylene	
Ficus elastica	Rubber Plant		Formaldehyde	
Ficus goldmanii	Ficus	Heavy Metals	Cu, Zn, Pb	Tree
Ficus infectoria	Wavy Leaf Fig Tree	Petroleum	TPH	Tree
Ficus pumila	Creeping/Climbing Fig	Petroleum	Unspecified	Vine
Firmiana simplex	Chinese parasol tree	Heavy Metals	Cd	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			Chowdhury R, Favas PJ, Pratas J, Jonathan MP, Ganesh PS, Sarkar SK. Accumulation of Trace Metals by Mangrove Plants in Indian Sundarban Wetland: Prospects for Phytoremediation. Int J Phytoremediation. 2015;17(9):885-894. doi:10.1080/15226514.2014.981244
Degradation	3–8	Europe	Banks and Schwab, 1998 Batty and Anslow, 2008 Chen and Banks, 2004 Cook and Hesterberg, 2012 Flathman and Lanza, 1998 Hutchinson et al., 2001 ITRC PHYTO 3 Karthikeyen et al., 2012 Kulakow, 2006d Liu et al., 2010 Ma et al., 2013 Olson et al., 2007 Parrish et al., 2004 Reilley et al., 1996 Reilley et al., 1993 Rice et al., 1996a Robinson et al., 2003 Roy et al., 2005 Schwab and Banks, 1994 Siciliano et al., 2003 Sun et al., 2011
Degradation	4–8	Europe	Duringer et al., 2010.
Extraction	3–8	Europe	Pavlikova et al., 2007
Accumulator	3–8	Europe	Batty and Anslow, 2008
Extraction	4–8	Europe	Dahlman et al., 1969 ITRC PHYTO 3
Accumulator			Majewska M, Jaroszuk-?cise? J. Mobilization of Cd from Festuca ovina roots and its simultaneous immobilization by soil in a root-soil-extractant system (in vitro test). Int J Phytoremediation. 2017;19(8):701-708. doi:10.1080/15226514.2017.1284744
			Mcintosh, Patrick, et al. "Breakdown of Low-Level Total Petroleum Hydrocarbons (TPH) in Contaminated Soil Using Grasses and Willows." International Journal of Phytoremediation, vol. 18, no. 7, 2015, pp. 656–663., doi:10.1080/15226514.2015.1109598.
Degradation	3–9	Europe, Asia	Cook and Hesterberg, 2012 Muratova et al., 2008
Degradation	4–10	North America, Europe	Cook and Hesterberg, 2012 Kulakow, 2006c Palmroth et al., 2006
Extraction	3–8	Northern USA	ITRC PHYTO 3 Salt et al., 1992
Excluder	3–8	Northern USA	Lasat, 2000
Degradation	Varies	Worldwide	Banks, 2006 Cook and Hesterberg, 2012 Kulakow, 2006b Kulakow, 2006e Tsao, 2006a Tsao, 2006b White et al., 2006
N/A			1) Plants "Clean" Air Inside Our Homes (kilde NASA) 3) Wolverton, B.C. (1996) How to Grow Fresh Air. New York: Penguin Books. 4) B. C. Wolverton and J.D. Wolverton. "Plants and Soil Microorganisms: Removal of Formaldehyde, Xylene, Ammonia From the Indoor EnvFement". Retrieved 2011-08-27.
Hyperaccumulator			1) Plants "Clean" Air Inside Our Homes (kilde NASA) 2) Wolverton, B.C. (1996) How to Grow Fresh Air. New York: Penguin Books.
Excluder	10+	Central America	Cortés-Jiménez et al., 2012
Degradation	Not available	India	Cook and Hesterberg, 2012 Yateem et al., 2008
Tolerance	9–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator/Tolerant			Kang W, Bao J, Zheng J, Xu F, Wang L. Phytoremediation of heavy metal contaminated soil potential by woody plants on Tonglushan ancient Cu spoil heap in China. Int J Phytoremediation. 2018;20(1):1-7. doi:10.1080/15226514.2014.950412

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Fraxinus	Ash		Polychlorinated Biphenyl (PCB)	
Fraxinus pennsylvanica	Green Ash	Petroleum	PAH	Tree
Fraxinus pennsylvanica	Green Ash	Petroleum	Unspecified	Tree
Fuchsia excorticate	Tree Fuschia	Heavy Metals	As	Tree
Furcraea gigantea vent.	Mauritius Hemp	Heavy Metals	Cr	
Gamblea innovans		Heavy Metals	Zn	
Gentiana pennelliana	Wiregrass Gentian	Heavy Metals	Pb, Cu, Zn	Herbaceous
Geranium viscosissimum	Sticky Geranium	Petroleum	PAH	Herbaceous
Gerbera jamesonii	Gerbera Daisy		Benzene, Formaldehyde, Trichloroethylene (TCE) and by-products	
Gleditsia triacanthos	Honey Locust	Petroleum	BTEX	Tree
Gleditsia triacanthos	Honey Locust	Heavy Metals	Pb	
Glycine max	Soybean	Chlorinated Sol-vents	Dodecyl linear alcohol ethoxylate Dodecyl linear alkylben-zene sulfonate Dodecyltrimethyl ammo-nium chloride TCE	Herbaceous
Glycine max	Soybean	Explosives	RDX TNT	Herbaceous
Glycine max	Soybean	POP	PCB	Herbaceous
Glycine max	Soybean	Heavy Metals	As, Co, Cu, Ni	
Gossypium spp.	Cotton	Pesticides	Temik	Herbaceous
Griselinia littoralis	Broadleaf	Heavy Metals	As	Shrub

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
N/A			1) Leigh, M.B., J. Fletcher, D.P. Nagle, P. Prouzova, M. Mackova and T. Macek (2003) Rhizoremediation of PCBS: Mechanistic and Field Investigations
Degradation	2–9	Eastern USA	Cook and Hesterberg, 2012 Spriggs et al., 2005
Tolerance	2–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Excluder	8–10	New Zealand	Craw et al., 2007
Accumulator			Ramana S, Biswas AK, Singh AB, Ahirwar NK, Prasad RD, Srivastava S. Potential of Mauritius Hemp (Furcraea gigantea Vent.) for the Remediation of Cr Contaminated Soils. Int J Phytoremediation. 2015;17(7):709-715. doi:10.1080/15226514.2014.964842
Accumulator			Sakurai M, Tomioka R, Hokura A, Terada Y, Takenaka C. Distributions of Cd, Zn, and polyphenols in Gamblea innovans. Int J Phytoremediation. 2019;21(3):217-223. doi:10.1080/15226514.2018.1524840
Excluder	8+	Florida	Yoon et al., 2006
Degradation	2+	Western North America	Olson et al., 2007
Hyperaccumulator			1) http://www.colostate.edu/Depts/CoopExt/4DMG/Plants/clean.htm 2)Plants "Clean" Air Inside Our Homes (kilde NASA)
Degradation	3–9	North America	Cook and Hesterberg, 2012 Fagiolo and Ferro, 2004
N/A			1) USDA NRCS Plant Materials Center, Manhattan, Kansas & Kansas State University, Forestry Researchhttp://plants.usda.gov/factsheet/pdf/fs_sani.pdf 2) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 3) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Degradation	Grown as annual	Eastern Asia	Anderson and Walton, 1991, 1992 Anderson et al., 1993 ITRC PHYTO 3
Degradation	Grown as annual	Eastern Asia	Adamia et al., 2006 Chen et al., 2011 Vila et al., 2007
Extraction	Grown as annual	Asia	McCutcheon and Schnoor, 2003
Accumulator			1) U.S EnvFemental Protection Agency (EPA). Phytoremediation field studies database for chlorinated solvents, pesticides, explosives, and metals. http://www.afcee.af.mil/shared/media/document/AFD-071130-018.pdf 3) Zhu S, Ma X, Guo R, et al. A field study on heavy metals phytoattenuation potential of monocropping and intercropping of maize and/or legumes in weakly alkaline soils. Int J Phytoremediation. 2016;18(10):1014-1021. doi:10.1080/15226514.2016.1183570 4) Fu, Yanzhao, et al. "Permeability of Plant Young Root Endodermis to Cu Ions and Cu-Citrate Complexes in Corn and Soybean." International Journal of Phytoremediation, vol. 17, no. 9, 2015, pp. 822–834., doi:10.1080/15226514.2014.981241.
Degradation or hydraulic control	8–11	Asia	Anderson et al., 1993 ITRC PHYTO 3
Excluder	8–9	New Zealand	Craw et al., 2007

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Guardiola tulocarpus	Guardiola	Heavy Metals	Cu, Zn, Pb	Herbaceous
Guercus gambelii	Gambel Oak	Chlorinated Solvents	Chlorinated Solvents, Pb, Pd, Plutonium, U	
Gynerium sagittatum	Wildcane	Heavy Metals	Cd, Hg, Cr, Pb- landfill leachate	
Gynura pseudochina	Purple Velvet Plant	Heavy Metals	Zn, Cd	Herbaceous
Hammada scoparia (Pomel) Ijin		Heavy Metals	Pb, Zn, Cu ,Cd	
Handroanthus impetiginosus	Pink Trumpet Tree	Heavy Metals	Zn, Cd, Cu, Pd	
Haplopappus (sect. Oonopsis) condensate	Haplopappus	Heavy Metals	Se	Herbaceous
Haplopappus (sect. Oonopsis) fremontii	Wards False Goldenweed	Heavy Metals	Se	Herbaceous
Hater Hyssop	Hater Hyssop	Heavy Metals	Cd, Cr, Cu, Pb, Hg	
Hedera helix	English Ivy	Petroleum	Unspecified	Herbaceous
Helianthus annus	Sunflower	Heavy Metals	As	Herbaceous
Helianthus annuus	Sunflower	Petroleum	PAH	Herbaceous
Helianthus annuus	Sunflower	Explosives	TNT	Herbaceous
Helianthus annuus L. cv. Ikarus Helianthus annuus	Sunflower	Heavy Metals	Cd, Zn, As, Ni	Herbaceous
Helianthus annuus Helianthus annuus 'Mammoth', 'SF-187'	Sunflower	Radionuclides	I, U, 226Ra, 238U, 90Sr, 238U, 137Cs	Herbaceous
Helianthus tuberosus	Jerusalem Artichoke	Heavy Metals	Cd	Herbaceous
Heliconia psittacorum	Parrott Heliconia		Cd, Hg, Cr, Pb- landfill leachate	
Hemerocallis hybrid	Daylily, dwarf yellow	Petroleum	Unspecified	Perennial
Hemerocallis hybrid	Daylily	Petroleum	Unspecified	Perennial

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Excluder	not available	Mexico, Southwestern USA	Cortés-Jiménez et al., 2012
N/A			1) Phytoremediation of Radionuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm
Accumulator			Madera-Parra CA, Peña-Salamanca EJ, Peña MR, Rousseau DP, Lens PN. Phytoremediation of Landfill Leachate with Colocasia esculenta, Gynerum sagittatum and Heliconia psittacorum in Constructed Wetlands. Int J Phytoremediation. 2015;17(1-6):16-24. doi:10.1080/15226514.2013.828014
Accumulator	10–11	Asia	Phaenark et al., 2009
Accumulator			Midhat L, Ouazzani N, Esshaimi M, Ouhammou A, Mandi L. Assessment of heavy metals accumulation by spontaneous vegetation: Screening for new accumulator plant species grown in Kettara mine-Marrakech, Southern Morocco. Int J Phytoremediation. 2017;19(2):191-198. doi:10.1080/15226514.2016.1207604
Tolerant			Meyer ST, Castro SR, Fernandes MM, Soares AC, de Souza Freitas GA, Ribeiro E. Heavy-metal-contaminated industrial soil: Uptake assessment in native plant species from Brazilian Cerrado. Int J Phytoremediation. 2016;18(8):832-838. doi:10.1080/15226514.2016.1146224
Hyperaccumulator	Not available	Western North America	Baker and Reeves, 2000 Byers, 1935
Hyperaccumulator	Not available	Western North America	Baker and Reeves, 2000 Byers, 1935 Rosenfeld and Beath, 1964
Accumulator, Hyperaccumulator			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Tolerance	5–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Potential Accumulators	Grown as annual	North and South America	McCutcheon and Schnoor, 2003
Degradation	Grown as annual	North America, South America	Cook and Hesterberg, 2012 Euliss, 2004
Degradation	Grown as annual	North America	Lee et al., 2007
Accumulator	Grown as annual	USA	Adesodun et al., 2010 Cutright et al., 2010 ITRC PHYTO 3 Kumar et al., 1995 Nehnevajova et al., 2005 Nehnevajova et al., 2007 Padmavathiamma and Li, 2009 Salt et al., 1995 Stritsis et al., 2014
Extraction	Grown as annual	North and South America	Dushenkov et al., 1997a, 1997b Soudek et al., 2004 Soudek et al., 2006a Soudek et al., 2006b Tome et al., 2008
Accumulator	3–9	Eastern USA	Chen et al., 2011
Accumulator			Madera-Parra CA, Peña-Salamanca EJ, Peña MR, Rousseau DP, Lens PN. Phytoremediation of Landfill Leachate with Colocasia esculenta, Gynerum sagittatum and Heliconia psittacorum in Constructed Wetlands. Int J Phytoremediation. 2015;17(1-6):16-24. doi:10.1080/15226514.2013.828014
Tolerance	3–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Tolerance	3–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Heteranthera dubia	Water Star-Grass	Explosives	RDX TNT	Herbaceous
Hibiscus cannabinus L.	Kenaf	Heavy Metals	As, Fe	Herbaceous
Hibiscus tiliaceus	Dwarf Hau	Petroleum	PAH	Tree/ Herbaceous
Hirschfeldia incana	Shortpod Mustard Hoary Mustard	Heavy Metals	As	Herbaceous
Hirschfeldia incana L. Lagreze-Fossat	Shortpod Mustard	Heavy Metals	Pb, Zn, Cu ,Cd	
Holcus mollis	Wild Millet	Radionuclides	134Cs	Herbaceous
Holoptelea integrifolia	Indian Elm	Heavy Metals	As	
Hordeum brachyantherum	Meadow barley		Trichloroethylene (TCE) and by-products	
Hordeum vulgare	Barley	Petroleum	TPH Pyrene	Herbaceous
Hordeum vulgarel	Barley	Heavy Metals	Sr	
Hydrangea macrophylla	Hydrangea	Heavy Metals	Al	
Hydrocharis morsus-ranae	Frogbit	Heavy Metals	Fe, Mn, Zn	
Hydrocharis morsus-ranae L.	European Frogbit	Heavy Metals	Cr, Cu, Pb, Mn, Hg	
Hydrocotyle vulgaris	Marsh pennywort	Other	Prometryn	
Hyrdilla verticillata	Waterthymes	Heavy Metals	As, Cd, Cu, Ni, Pb, Zn	
Ilex cornuta	Dwarf Burford Holly	Petroleum	Unspecified	Shrub
Ilex vomitoria	Yaupon Holly	Petroleum	Unspecified	Shrub

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation	6–11	North and Central America	Best et al., 1997
Excluder	10+	Southern Asia	Meera and Agamuthu, 2011
Degradation	10–12	Australia	Cook and Hesterberg, 2012 Paquin et al., 2002
Potential Accumulators	6–9	Spain, Mediterranean	Gisbert et al., 2008
Accumulator			Midhat L, Ouazzani N, Esshaimi M, Ouhammou A, Mandi L. Assessment of heavy metals accumulation by spontaneous vegetation: Screening for new accumulator plant species grown in Kettara mine-Marrakech, Southern Morocco. Int J Phytoremediation. 2017;19(2):191-198. doi:10.1080/15226514.2016.1207604
Extraction	6–9	Northern Europe	ITRC PHYTO 3 Salt et al., 1992
Accumulator			Kumar D, Singh VP, Tripathi DK, Prasad SM, Chauhan DK. Effect of As on Growth, As Uptake, Distribution of Nutrient Elements and Thiols in Seedlings of Wrightia arborea (Dennst.) Mabb. Int J Phytoremediation. 2015;17(1-6):128-134. doi:10.1080/15226514.2013.862205
N/A			1) Jordahl, J., R. Tossell, M. Barackman and G. Vogt (2003) Phytoremediation for Hydraulic Control and Remediation: Beale 2) Air Force Base and Koppel Stockton Terminal. Abstracts from US EPA International Applied Phytotechnologies Workshop March 3-5, 2003 Chicago, IL
Degradation	Grown as annual	Asia, North Africa	Cook and Hesterberg, 2012 Muratova et al., 2008 White and Newman, 2011
Accumulator			1) McCutcheon & Schnoor 2003, Phytoremediation. New Jersey, John Wiley & Sons pg 891. 2) Qi L, Qin X, Li FM, et al. Uptake and distribution of stable Sr in 26 cultivars of three crop species: oats, wheat, and barley for their potential use in phytoremediation. Int J Phytoremediation. 2015;17(1-6):264-271. doi:10.1080/15226514.2014.898016
Indicator			1) http://en.wikipedia.org/wiki/List_of_hyperaccumulators
Accumulator			Engin MS, Uyanik A, Kutbay HG. Accumulation of heavy metals in water, sediments and wetland plants of kizilirmak delta (samsun, Turkey). Int J Phytoremediation. 2015;17(1-6):66-75. doi:10.1080/15226514.2013.828019
N/A			1) McCutcheon & Schnoor 2003, Phytoremediation. New Jersey, John Wiley & Sons, page 898.
Tolerant			Ni J, Sun SX, Zheng Y, Datta R, Sarkar D, Li YM. Removal of prometryn from hydroponic media using marsh pennywort (Hydrocotyle vulgaris L.). Int J Phytoremediation. 2018;20(9):909-913. doi:10.1080/15226514.2018.1448359
Accumulator of metals, Hyperaccumulator of metals			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf 2) Phytoremediation of RadioÂ¬nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm 3) Lu G, Wang B, Zhang C, et al. Heavy metals contamination and accumulation in submerged macrophytes in an urban river in China. Int J Phytoremediation. 2018;20(8):839-846. doi:10.1080/15226514.2018.1438354
Tolerance	7–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Tolerance	7–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Impatiens bicolor royale	Royal Impatiens	Heavy Metals	Cr, Ni, Fe, Mn, Co, Cu, Zn	
Impatiens violaeflora Impatiens walleriana Hook. f.	Impatiens	Heavy Metals	Cd	Herbaceous
Impatients walleriana	Impatiens	Petroleum	Benzene, Cr	
Inbred B37 Zea mays	Corn (b37 Maize)	Heavy Metals	Cd	
Inga laurina	Sacky Sac Bean	Heavy Metals	Zn, Cd, Cu, Pd	
Inula viscosa (Dittrichia viscosa)	Sticky Fleabane Yellow Fleabane	Heavy Metals	As	Herbaceous
Ipomoea carnea	Pink Morning Glory	Heavy Metals	Fe, Mn, Cu, Pb, Cr, Ni, Cd	
Iris dichotoma Pall	Blackberry Lily	Petroleum	Petroleum hydrocarbons	
Iris germanica	Bearded Iris	Heavy Metals	Al, As, Cd, Cu, Flourine, Mn, Zn	
Iris lactea Pall	Japanese Water Iris	Petroleum	Petroleum hydrocarbons	
Iris pseudacorus	Yellow Flag	Pesticides	Atrazine	Wetland
Iris pseudacorus	Pale Yellow Iris	Heavy Metals	Al, As, Atrazine, Beryllium, Cd, Cu, Mn	
Iris pseudacorus L.	Yellow Flag	Heavy Metals	Cr, Ni	
Iris spp.	Iris	Pesticides	Atrazine	Herbaceous
Iris versicolor	Blue Flag Iris	Pesticides	Chlorpyrifos Chloro-thalonil Pendimethalin Propiconazole	Herbaceous
Isatis capadocica	Isatis capadocica	Heavy Metals	As	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			Nawab J, Khan S, Shah MT, Khan K, Huang Q, Ali R. Quantification of Heavy Metals in Mining Affected Soil and Their Bioaccumulation in Native Plant Species. Int J Phytoremediation. 2015;17(9):801-813. doi:10.1080/15226514.2014.981246
Accumulator	Not available		Lin et al., 2010 Phaenark et al., 2009
Accumulator, Hyperaccumulator			1) Lai HY, Cai MC. Effects of extended growth periods on subcellular distribution, chemical forms, and the translocation of Cd in Impatiens walleriana. Int J Phytoremediation. 2016;18(3):228-234. doi:10.1080/15226514.2015.1073677 2) Campos V, Lessa SS, Ramos RL, Shinzato MC, Medeiros TAM. Disturbance response indicators of Impatiens walleriana exposed to benzene and Cr. Int J Phytoremediation. 2017;19(8):709-717. doi:10.1080/15226514.2017.1284745
Accumulator			(Phyto Textbook) Broadhurst, C.l., Chaney, R. L., Davis, A. P., Cox, A., Kumar, K., Reeves, R. D., and Green, C. E. 2013 Growth and Cd phytoextraction by Swiss chard, maize, rice, Noccaea caerulescens and Alyssum murale in pH adjusted biosolids amended soils. International Journal of Phytoremediation, DOI, 10.1080/15226514.2013.828015.
Tolerant			Meyer ST, Castro SR, Fernandes MM, Soares AC, de Souza Freitas GA, Ribeiro E. Heavy-metal-contaminated industrial soil: Uptake assessment in native plant species from Brazilian Cerrado. Int J Phytoremediation. 2016;18(8):832-838. doi:10.1080/15226514.2016.1146224
Potential Accumulators	9–11	Spain, Mediterranean	Gisbert et al., 2008
Accumulator			Pandey SK, Bhattacharya T, Chakraborty S. Metal phytoremediation potential of naturally growing plants on fly ash dumpsite of Patratu thermal power station, Jharkhand, India. Int J Phytoremediation. 2016;18(1):87-93. doi:10.1080/15226514.2015.1064353
			Cheng L, Wang Y, Cai Z, Liu J, Yu B, Zhou Q. Phytoremediation of petroleum hydrocarbon-contaminated saline-alkali soil by wild ornamental Iridaceae species. Int J Phytoremediation. 2017;19(3):300-308. doi:10.1080/15226514.2016.1225282
Hyperaccumulator, Accumulator of As			1) University of Minnesota Sustainable Urban Landscape Information Series. http://www.sustland.umn.edu/design/water4.html
			Cheng L, Wang Y, Cai Z, Liu J, Yu B, Zhou Q. Phytoremediation of petroleum hydrocarbon-contaminated saline-alkali soil by wild ornamental Iridaceae species. Int J Phytoremediation. 2017;19(3):300-308. doi:10.1080/15226514.2016.1225282
Degradation or hydraulic control	4–9	Europe, Asia, Africa	Wang et al., 2012
Accumulator of Cd, Mn, Al, As, and Beryllium. Hyperaccumulator of Cu			2) (Phyto Textbook) WAng, Q., Zhang, W., Li, L., and Xiao, B. 2012. Phytoremediation of atrazine by three emergent hydrophytes in a hydroponic system. Water Science and Technology66 (6), pp. 1282-1288.
			Xu B, Yu S, Ding J, Wu S, Ma J. Metal-Dependent Root Fe Plaque Effects on Distribution and Translocation of Cr and Ni in Yellow Flag (Iris pseudacorus L.). Int J Phytoremediation. 2015;17(1-6):175-181. doi:10.1080/15226514.2013.876965
Degradation or hydraulic control	varies	varies	Burken and Schnoor, 1997
Degradation or hydraulic control	4–7	Northern North America	Smith et al., 2008
Potential Accumulators	not available	Iran	Karimi et al., 2009

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Isoetes lacustris	Lake Quillwort	Heavy Metals	Cu, Pb	
Jatropha curcas L with Acaulospora sp. fungus	Spurge	Heavy Metals	Cd, Pb, Zn	
Jatropha curcas L.	Barbados Nut	Heavy Metals	Al, Cu, Pb, Zn, Cd	Tree/Shrub
Juncus balticus	Baltic Rush	Heavy Metals	Cu	
Juncus effuses	Soft Rush	Organics	Ammonia, Anthracene, As, Nitrate, N, Phosphate	
Juncus effusus	Common Rush	Petroleum	PAH	Wetland
Juncus glaucus	Blue Rush	Explosives	TNT	Herbaceous
Juncus maritimus	Sea rush	Petroleum	Petroleum hydrocarbons	
Juniperus flaccid	Mexican Juniper	Heavy Metals	Cu, Zn, Pb	Tree
Juniperus monosperma	Oneseed Juniper	Radionuclides	U	Shrub/Tree
Juniperus procumbens	Juniper	Petroleum	Unspecified	Shrub
Juniperus virginiana	Eastern Red Cedar	Petroleum	BTEX	Tree
Jussiaea repens	Floating Primrose Willow	Heavy Metals	As	Herbaceous
Justicia procumbens	Water Willow	Heavy Metals	Cd, Zn	Herbaceous
Kalimeris integrifolia	Japanese Aster	Heavy Metals	Cd	Herbaceous
Kochia scoparia	Burningbush	Petroleum	TPH	Shrub
Kochia spp.		Pesticides	Atrazine Metolachlor Trifluralin	Herbaceous
Lactuca sativa cv. Cos	Lettuce	Heavy Metals	As	Herbaceous
Lagenaria siceraria	Calabash, Gourd	POP	Heptachlor Heptachlor epoxide	Herbaceous
Lagerstroemia fauriei	Japanese Crape Myrtyle	Heavy Metals	Cd	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
N/A			1) W. Carl Taylor @ USDA-NRCS plant database. (1992) http://wisplants.uwsp.edu/scripts/detail.asp?SpCode=ISOLAC 2) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 3) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Accumulator			González-Chávez MD, Carrillo-González R, Hernández Godínez MI, Evangelista Lozano S. Jatropha curcas and assisted phytoremediation of a mine tailing with biochar and a mycorrhizal fungus. Int J Phytoremediation. 2017;19(2):174-182. doi:10.1080/15226514.2016.1207602
Excluder	11	Central America	Wu et al., 2011
N/A			1) Gallagher, J.L and H.V. Kibby, 1980. Marsh plants as vectors in trace metal transport in Oregon tidal marshes. American Journal of Botany, 67: 1069-1074
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant_species_phyto.pdf http://www.flickr.com/photos/gruts/5974723340/" Soft rushes by Richard Carter, on Flicker http://farm7.staticflickr.com/6143/5974723340_23d59905f0jpg
Degradation	2–9	Worldwide	Cook and Hesterberg, 2012 Euliss, 2004
Degradation	4–9	Europe	Nepovim et al., 2005 Vanek et al., 2006
Accumulator			(Phyto Textbook) Ribeiro, H., Almeida, C., Mucha, A., ad Bordalo, A. 2013. Influence of different salt marsh plants on hydrocarbon degrading microorganisms abundance throughout a phenological cycle. International Journal of Phytoremediation 15 (3), pp. 245-256.
Excluder	8+	Mexico, Southwestern USA	Cortés-Jiménez et al., 2012
Extraction	4+	Western USA	Ramaswami et al., 2001
Tolerance	4–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Degradation	2–9	Eastern USA	Cook and Hesterberg, 2012 Fagiolo and Ferro, 2004
Potential Accumulators	8–11	North America	Molla et al., 2010
Accumulator	Not available	Thailand, India	Phaenark et al., 2009, 2011
Accumulator	5–9	Asia	Wei and Zhou, 2008
Degradation	9–11	Europe, Asia	Zand et al., 2010
Degradation or hydraulic control	varies	Europe, Asia	Anderson et al., 1994 ITRC PHYTO 3
Potential Accumulators	Grown as annual	Europe, Asia	ITRC PHYTO 3 Speir et al., 1992
Extraction	Grown as annual	Asia, Africa	Campbell et al., 2009
Accumulator			Wang Y, Gu C, Bai S, et al. Cd accumulation and tolerance of Lagerstroemia indica and Lagerstroemia fauriei (Lythraceae) seedlings for phytoremediation applications. Int J Phytoremediation. 2016;18(11):1104-1112. doi:10.1080/15226514.2016.1183581

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Lagerstroemia floribunda	Crepe myrtle	Heavy Metals	Pb	
Lagerstroemia indica	Dwarf Crape Myrtle	Petroleum	Unspecified	Shrub
Lamarckia aurea L. Moench	Golden Dogs tail	Heavy Metals	Pb, Zn, Cu ,Cd	
Lantana camara	Verbena	Heavy Metals	Fe, Mn, Cu, Pb, Cr, Ni, Cd	
Lantana montevidensis	Creeping Lantana	Petroleum	Unspecified	Herbaceous
Lecythis ollaria	Coco de Mono	Heavy Metals	Se	Tree
Leersia oryzoides	Rice Cutgrass	Heavy Metals	As	Herbaceous
Legume	Legume		Trichloroethylene (TCE) and by-products	
Lemna gibba	Gibbous Duckweed	Heavy Metals	Cr, Cd	Herbaceous
Lemna minor	Duckweed	Pesticides	Demeton-8-methyl Malathion Metolachlor Cu sulfate Dimethomorph Flazasulfron Isoproturon Glyphosate	Herbaceous
Lemna minor	Lesser Duckweed	Heavy Metals	Cd, Cu, Pb, Ni	Herbaceous
Lemna minuta Kunth	Duckweed	Petroleum	Direct blue 129 diazo dye (DB129)	Herbaceous
Lepidium sativum L.	Garden cress	Heavy Metals	Hg	
Leptoplax emarginata	Leptoplax	Heavy Metals	Ni	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			(Phyto Textbook) Meeinkuirt, W., Pokethitiyook, P., Kruatrachue, M., Tanhan, P., and Chairy-arat, R. 2012. Phytostabilization of a Pb-contaminated mine tailing by various tree species in pot and field trial experiments. International Journal of Phytoremediation 14 (9), pp. 925–938.
Tolerance	7–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator			Midhat L, Ouazzani N, Esshaimi M, Ouhammou A, Mandi L. Assessment of heavy metals accumulation by spontaneous vegetation: Screening for new accumulator plant species grown in Kettara mine-Marrakech, Southern Morocco. Int J Phytoremediation. 2017;19(2):191-198. doi:10.1080/15226514.2016.1207604
Accumulator			Pandey SK, Bhattacharya T, Chakraborty S. Metal phytoremediation potential of naturally growing plants on fly ash dumpsite of Patratu thermal power station, Jharkhand, India. Int J Phytoremediation. 2016;18(1):87-93. doi:10.1080/15226514.2015.1064353
Tolerance	8–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Hyperaccumulator	Not available	Venezuela, Brazil	Baker and Reeves, 2000 Aronow and Kerdel-Vegas, 1965
Potential Accumulators	3–9	North America	Ampiah-Bonney and Tyson, 2007
N/A			1) Walton, B.T and Anderson, T.A. 1990. "Microbial Degradation of Trichloroethylene in the Rhizosphere: Potential Application to Biological Remediation of Waste Sites". Applied and EnvFemental Microbiology, Apr 1990, p. 1012-1016. Kim, RH et. Al. (2003) Remediation of VOC-Contaminated Groundwater at the Savannah River Site by Phyto-Irrigation. Abstracts from US EPA International Applied Phytotechnologies Workshop March 3-5, 2003 Chicago, IL
Hyperaccumulator			Chaudhary E, Sharma P. Cr and Cd removal from wastewater using duckweed - Lemna gibba L. and ultrastructural deformation due to metal toxicity. Int J Phytoremediation. 2019;21(3):279-286. doi:10.1080/15226514.2018.1522614
Degradation or hydraulic control	3+	Worldwide	Dosnon-Olette et al., 2011 Gao et al., 1998 ITRC PHYTO 3 Olette et al., 2008 Rice et al., 1996b
Accumulator			1) USDA NRCS Plant Materials Center, Manhattan, Kansas & Kansas State University, Forestry Researchhttp://plants.usda.gov/factsheet/pdf/fs_sani.pdf 2) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 3) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf 4) Journal of EnvFemental Science and Technology 4 (2): 118-138, 2011 ISSN 1994-7887/ DOI: 10. 3923/jest.2011.118.138 http://scialert.net/qredirect.php?doi=jest.2011.118.138&linkid=pdf (Source for Cr) 7) (Phyto Textbook) Teixeira, S., Vieira, M. N., Marques, J. E.,
Tolerant			Chiudioni F, Trabace T, Di Gennaro S, Palma A, Manes F, Mancini L. Phytoremediation applications in natural condition and in mesocosm: The uptake of Cd by Lemna minuta Kunth, a non-native species in Italian watercourses. Int J Phytoremediation. 2017;19(4):371-376. doi :10.1080/15226514.2016.1225290
Accumulator			Smolinska B, Szczodrowska A, Leszczynska J. Protein changes in Lepidium sativum L. exposed to Hg during soil phytoremediation. Int J Phytoremediation. 2017;19(8):765-773. doi :10.1080/15226514.2017.1284754
Hyperaccumulator	Not available	Greece	Chardot et al., 2005

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Leptospermum scoparium	Manuka	Heavy Metals	As	Shrub
Lersia oryzoides	Rice Cutgrass	Explosives	RDX	Herbaceous
Lespedeza cuneata	Bush Clover	Chlorinated Sol-vents	TCE	Herbaceous
Lespedeza cuneata	Chinese Bushclover	Heavy Metals	Zn, Pb ,Cu	Shrub
Leucaena leucocephala	River tamarind	Heavy Metals	Zn, Cd	
Leymus angustus	Altai Wildrye	Petroleum	TPH	Herbaceous
Ligustrum japonicum	Waxleaf Ligustrum	Petroleum	Unspecified	Shrub
Ligustrum lucidum	Privet	Heavy Metals	Cd	
Limonastrium monopetalum	Limonastrium	Heavy Metals	Cd	Herbaceous
Limoniastrum monopetalum	Limoniastrum	Heavy Metals	Cd, Pb	
Linum spp.	Flax	Pesticides	2,4-D	Herbaceous
Linum usitatissimum L. ssp. usutatissimum cv. Gold Merchant	Flax	Heavy Metals	Cd	Herbaceous
Linum usitatissumum L.	Flax	Petroleum	TPH	Herbaceous
Liquidambar formosana Hance	Chinese Sweet Gum	Heavy Metals	Zn, Pb ,Cu	
Liquidambar styraciflua	Sweetgum	Chlorinated Sol-vents	TCE	Tree
Liquidamber stryaciflua	Sweet Gum	Radionuclides	226Ra	Tree
Liriodendron tulipifera	Tulip Poplar	Radionuclides	226Ra	Tree

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Excluder	9–10	New Zealand	Craw et al., 2007
Degradation	3–8	North America, Europe, Asia	Kiker and Larson, 2001
Degradation	5–11	Eastern Asia	Anderson and Walton, 1991, 1992 ITRC PHYTO 3
Accumulator			Shi X, Chen YT, Wang SF, et al. Phytoremediation potential of transplanted bare-root seedlings of trees for Pb/Zn and Cu mine tailings. Int J Phytoremediation. 2016;18(11):1155-1163. doi:10.1080/15226514.2016.1189399
Accumulator/Tolerant			1) (Phyto Textbook) Meeinkuirt, W., Pokethitiyook, P., Kruatrachue, M., Tanhan, P., and Chairyarat, R. 2012. Phytostabilization of a Pb-contaminated mine tailing by various tree species in pot and field trial experiments. International Journal of Phytoremediation 14 (9), pp. 925-938. 2) Rangel WM, Thijs S, Janssen J, et al. Native rhizobia from Zn mining soil promote the growth of Leucaena leucocephala on contaminated soil. Int J Phytoremediation. 2017;19(2):142-156. doi:10.1080/15226514.2016.1207600
Degradation	2–8	Europe, Asia	Cook and Hesterberg, 2012 Phillips et al., 2009
Tolerance	7–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator/Tolerant			1) Kang W, Bao J, Zheng J, Xu F, Wang L. Phytoremediation of heavy metal contaminated soil potential by woody plants on Tonglushan ancient Cu spoil heap in China. Int J Phytoremediation. 2018;20(1):1-7. doi:10.1080/15226514.2014.950412 2) Zeng P, Guo Z, Cao X, Xiao X, Liu Y, Shi L. Phytostabilization potential of ornamental plants grown in soil contaminated with Cd. Int J Phytoremediation. 2018;20(4):311-320. doi:10.1080/15226514.2017.1381939
Accumulator	10–11	Greece	Manousaki et al., 2014
Tolerant			(Phyto Textbook) Manousaki, E., Galanaki, K., Papadimitriou, L., and Kalogerakis, N. 2014. Metal Phytoremediation by the Halophyte Limoniastrum monopetalum (L.) Boiss: Two Contrasting Ecotypes. International Journal of Phytoremediation 16 (7-8), pp. 755-769.
Degradation or hydraulic control	5–9	varies	Anderson et al., 1993 ITRC PHYTO 3
Accumulator	4–10	Mediterranean Middle East	Stritsis et al., 2014
Degradation	4–11	Europe, Asia	Zand et al., 2010
Accumulator			Shi X, Chen YT, Wang SF, et al. Phytoremediation potential of transplanted bare-root seedlings of trees for Pb/Zn and Cu mine tailings. Int J Phytoremediation. 2016;18(11):1155-1163. doi:10.1080/15226514.2016.1189399
Degradation	5–10	Eastern/ Southeastern USA	Stanhope et al., 2008 Strycharz and Newman, 2009b
Extraction	5–10	Eastern USA	ITRC PHYTO 3 Pinder et al., 1984
Extraction	5–10	Eastern USA	ITRC PHYTO 3 Pinder et al., 1984

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Liriodendron tulipifera	Tulip Tree	Heavy Metals	Cs, Formaldehyde, Plutonium, Polychlorinated Biphenyl (PCB), Sr, Trichloroethylene (TCE) and by-products, Vinyl Chloride, Xylene	
Liriope muscari	Aztec Grass	Petroleum	Unspecified	Herbaceous
Liriope muscari	Lily Turf	Petroleum	Unspecified	Herbaceous
Littorella uniflora	American Shoreweed	Heavy Metals	Cu, Pb	Herbaceous
Llex cornuta	Dwarf Burford Holly	Petroleum	Petroleum	
Llex ssp.	Holly	Heavy Metals	Cd	
Llex vomitoria	Yaupon Holly	Petroleum	Petroleum	
Lolium multiflorum	Annual Rye	Petroleum	TPH PAH	Herbaceous
Lolium multiflorum	Ryegrass	Explosives	HMX TNT	Herbaceous
Lolium multiflorum	Ryegrass	POP	p,p'-DDE (Weathered DDT)	Herbaceous
Lolium perenne	Herbaceous Ryegrass	Petroleum	Acenaphthene Benzo(a) anthracene Benzo(a) pyrene Benzo(b)fluoranthene Benzo(ghi)perylene, Benzo(k)fluoranthene Chrysene Dibenzo(ah) anthracene Fluoranthene Indeno(123cd)pyrene Naphthalene Pyrene TPH PAH BTEX PAE	Herbaceous
Lolium perenne	Perennial Ryegrass	Chlorinated Solvents	Pentachlorophenol	Herbaceous
Lolium perenne	Perennial Ryegrass	Explosives	HMX	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			1) Phytoremediation of Radio nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm 3) Ferro, A., Chard, B., Gefell, M., Thompson, B., and R. Kjelgren. 2000"Phytoremediation of Organic Solvents in Groundwater: Pilot Study at a Superfund Site . In: G. Wickramanayake, A. Gavaskar, B. Alleman, and V. Magar (eds.) Bioremediation and Phytoremediation of Chlorinated and Recalcitrant Compounds, p461-466. Battelle Press, Columbus, Ohio.; Ferro, A., Kennedy, J., Kjelgren, R., Rieder, J., and S. Perrin. 1999. "Toxicity Assessment of Volatile Organic Compounds in Poplar Trees" . International Journal of Phytoremediation. 1(19-17
Tolerance	6–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Tolerance	6–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf 2) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm
Tolerant			1) Analysis of Phytoscapes Species for BP Retail Sites. Kim Tsao. David Tsao, Ph.D. BP Group EnvFemental Management Company. 28 March 2003
Accumulator			1) Institute for EnvFemental Research and education (IERE). (2003 January). Vashon Heavy Metal Phytoremediation Study Sampling and Analysis Strategy (DRAFT). http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Tolerant			1) Analysis of Phytoscapes Species for BP Retail Sites. Kim Tsao. David Tsao, Ph.D. BP Group EnvFemental Management Company. 28 March 2003
Degradation	5+	Europe	Cook and Hesterberg, 2012 Flathman and Lanza, 1998 ITRC PHYTO 3 Lalande et al., 2003 Parrish et al., 2004
Degradation	5+	Europe	Adamia et al., 2006
Extraction	5+	Europe	White, 2000
Degradation	3–9	Europe, Asia	Binet et al., 2000 Cook and Hesterberg, 2012 Ferro et al., 1999 Ferro et al., 1997 Fu et al., 2012 Gunther et al., 1996 ITRC PHYTO 3 Johnson et al., 2005 Kulakow, 2006a Kulakow, 2006c Ma et al., 2013 Olson et al., 2007 Palmroth et al., 2006 Reynolds, 2006a Reynolds, 2006b Reynolds, 2006c Reynolds, 2006d Reynolds, 2006e Rezek et al., 2009 Yateem, 2013
Degradation	3–9	Europe	Ferro et al., 1997 ITRC PHYTO 3
Degradation	3–9	Europe, Asia	Duringer et al., 2010

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Lolium perenne	Perennial Ryegrass	Heavy Metals	As, Cu, Pb, Zn	Herbaceous
Lolium perenne – Fiesta 4	Rye grass	Petroleum	Total petroleum hydro-carbons	Herbaceous
Lolium perenne L.	Perennial Rye Grass	Other	Phthalate esters	Herbaceous
Lolium perenne Lolium perenne 'Premo'	Perennial Ryegrass	Radionuclides	134Cs, 58Co	Herbaceous
Lolium spp.	Ryegrass	Petroleum	TPH PAH	Herbaceous
Lolium spp.	Ryegrass	Heavy Metals	Cu	Herbaceous
Loropetalum chinense var. rubrum	Chinese fringe flower	Heavy Metals	Cd	
Lotus corniculatus	Birdsfoot Trefoil	Petroleum	TPH PAH	Herbaceous
Lupinus albus	White Lupin	Heavy Metals	As, N	
Lycopersicon esculentum	Tomato	Radionuclides	Co, Rb, Sr, Cs	Herbaceous
Lythrum salicaria	Purple Loosestrife	Pesticides	Atrazine	Wetland
Macfadyena unguis-cati	Yellow Trumpet Vine	Petroleum	Unspecified	Vine
Machaeranthera (Xylorhiza) glabriuscula	Smooth Woodyaster	Heavy Metals	Se	Herbaceous
Machaeranthera (Xylorhiza) venusta	Cisco Woodyaster	Heavy Metals	Se	Herbaceous
Machaeranthera parryi	Machaeranthera	Heavy Metals	Se	Herbaceous
Machaeranthera ramosa	Machaeranthera	Heavy Metals	Se	Herbaceous
Machaeranthera venusta	Machaeranthera	Heavy Metals	Se	Herbaceous
Maclura panifera	Osage Orange	POP	PCB	Tree
Maclura pomifera	Osage Orange		Polychlorinated Biphenyl (PCB)	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator/Tolerant			1) Oyler, J. Blue Mountain Superfund Remediation Project, Palmerton, PA. Powerpoint presentation. June 10, 2004. ITRC Phytotechnologies conference. 2) Groom, C.A, A. Halasz, L. Paquet, N. Morris, L. Olivier, C. Dubois and J. Hawari (2002) Accumulation of HMX (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine) in Indigenous and Agricultural Plants Grown in HMX- Contaminated Anti-Tank Firing-Range Soil. EnvFe. Sci. & Technol. 2002, Vol 36, Issue 1 p112-118 4) (Phyto Textbook) Fu, D., Teng, Y., Shen, Y., Sun, M., Tu, C., Luo, Y., Li, Z., and Christie, P. 2012. Dissipation of polycyclic aromatic hydrocarbons and microbial activity in a field soil planted with perennial ryegrass. Frontiers of Envrionmental Science and Engineering 6 (3) pp. 330-335. 5) (Phyto Textbook) Wang, K., Huang, H., Zhu, Z., Li, T., He, Z., Yang, X., and Alva, A. 2013. Phytoextraction of Metals and Rhizoremediation of PAHs in Co-Contaminate
			Mcintosh, Patrick, et al. "Breakdown of Low-Level Total Petroleum Hydrocarbons (TPH) in Contaminated Soil Using Grasses and Willows." International Journal of Phytoremediation, vol. 18, no. 7, 2015, pp. 656–663., doi:10.1080/15226514.2015.1109598.
Accumulator			(Phyto Textbook) Ma, T. T., Teng, Y., Luo, Y. M., and Christie, P. 2013. Legume-grass inter-cropping phytoremediation of phthalic acid esters in soil near an electronic waste recycling site: a field study. International Journal of Phytoremediation 15 (2), pp. 154-167.
Extraction	Grown as annual	Europe, Asia	ITRC PHYTO 3 Macklon and Sim, 1990 Salt et al., 1992
Degradation	Varies	Europe, Asia, North Africa	Banks, 2006 Kulakow, 2006e Muratova et al., 2008 Nedunuri et al., 2000 Tsao, 2006a Tsao, 2006b White et al., 2006
Excluder	3+	Europe	Ulrikson et al., 2012
			Zeng P, Guo Z, Cao X, Xiao X, Liu Y, Shi L. Phytostabilization potential of ornamental plants grown in soil contaminated with Cd. Int J Phytoremediation. 2018;20(4):311-320. doi:10.1080/15226514.2017.1381939
Degradation	5+	Europe	Karthikeyen et al., 2012 (5) Smith et al., 2006
N/A			1) Esteban, E, Vazquez, S and Carpena, R. (2003) White Lupin Response to Arsenate. University of Madrid, Spain
Extraction	Grown as annual	South America	Gouthu et al., 1997
Degradation or hydraulic control	3+	Europe, Asia	Wang et al., 2012
Tolerance	9–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Hyperaccumulator	4–5	Western North America	Baker and Reeves, 2000 Rosenfeld and Beath, 1964
Hyperaccumulator	7	Utah, Colorado	Baker and Reeves, 2000
Hyperaccumulator	Not available	Western North America	Baker and Reeves, 2000 Byers, 1935
Hyperaccumulator	Not available	Western North America	Baker and Reeves, 2000 Rosenfeld and Beath, 1964
Hyperaccumulator	Not available	Utah, Colorodo	Rosenfeld and Beath, 1964
Extraction	4–9	North America	Olson et al., 2003
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Malachium aquaticum	Water chickweed	Heavy Metals	Cd	Herbaceous
Medicago sativa	Alfalfa	POP	p,p'-DDE (Weathered DDT)	Herbaceous
Medicago sativa	Alfalfa	Heavy Metals	Zn, Cd, Ni	Herbaceous
Medicago sativa Medicago sativa Mesa var. Cimarron VR	Alfalfa	Petroleum	Anthracene Ethylene glycol MTBE Phenol PAH (total priority) Pyrene Toluene TPH PAH Benzene PAE	Herbaceous
Medicago truncatula L.	Barrel Clover	Radionuclides	Th, U	Herbaceous
Megathyrsus maximus cvs. Aruana & Tanzania	Guinea grass	Heavy Metals	Cd	Herbaceous
Melampyrum sylvaticum	Cow Wheat	Radionuclides	137Cs	Herbaceous
Melastoma malabathricum	Malabar Melastome Straits Rhododendron	Heavy Metals	As	Herbaceous
Melastoma malabathricum L.	Blue Tongue	Heavy Metals	Pb, As	
Melia azedarach	Chinaberry Tree	Heavy Metals	Cu, Pb, Cd	
Melilotus officinalis	Sweet Clover	Petroleum	TPH PAH	Herbaceous
Melilotus officinalis	Sweet Clover	Radionuclides	Cs	Herbaceous
Melilotus sulcata Desf.		Heavy Metals	Pb, Zn, Cu ,Cd	
Mentha spicata	Spearmint	POP	PCB	Herbaceous
Menyanthes trifoliate	Buckbean	Radionuclides	137Cs	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			He J, Lin L, Ma Q, et al. Uniconazole (S-3307) strengthens the growth and Cd accumulation of accumulator plant Malachium aquaticum. Int J Phytoremediation. 2017;19(4):348-352. doi:10.1080/15226514.2016.1225287
Extraction	3–11	Middle East	White, 2000
Accumulator	3–11	Asia	ITRC PHYTO 3 Tiemann et al., 1998 Videa-Peralta and Ramon, 2002
Degradation	3–11	Middle East	Cook and Hesterberg, 2012 Davis et al., 1994 Ferro et al., 1997 ITRC PHYTO 3 Komisar and Park, 1997 Liu et al., 2010 Ma et al., 2013 Muralidharan et al., 1993 Muratova et al., 2008 Phillips et al., 2009 Pradhan et al., 1998 Reilley, Banks and Schwab, 1993 Rice et al., 1996a Schwab and Banks, 1994 Sun et al., 2011 Tossell, 2006 Tsao, 2006a Tsao, 2006b Yateem, 2013
Extraction	Not available	Mediterranean	Chen et al., 2005
Accumulator, Tolerant			1) Nardis BO, Silva EB, Grazziotti PH, Alleoni LRF, Melo LCA, Farnezi MMM. Availability and Zn accumulation in forage grasses grown in contaminated soil. Int J Phytoremediation. 2018;20(3):205-213. doi:10.1080/15226514.2017.1365347 2) Silva EB, Fonseca FG, Alleoni LR, Nascimento SS, Grazziotti PH, Nardis BO. Availability and toxicity of Cd to forage grasses grown in contaminated soil. Int J Phytoremediation. 2016;18(9):847-852. doi:10.1080/15226514.2016.1146225
Extraction	6	Britain, Ireland	ITRC PHYTO 3 Olsen, 1994
Potential Accumulators	10–13	Indonesia, Asia	Selamat et al., 2013
Accumulator, Precipitator			1) Toshihiro Watanabe, Mitsuru Osaki, Teruhiko Yoshihara and Toshiaki Tadano (April 1998). "Distribution and chemical speciation of Al in the Al accumulator plant, Melastoma malabathricum L.". Plant and Soil 201 (2): 165â€"173. doi:10.1023/A:1004341415878. http://www.springerlink.com/content/t7080538256p0303/. 2) (Phyto Textbook) Selamat, S. N., Abdullah, S. R. S., and Idris, M. 2013. Phytoremediation of Pb (Pb) and As (As) by Melastoma malabathricum L. from Contaminated Soil in Separate Exposure. International Journal of Phytoremediation 16, pp. 694-703.
Accumulator/Tolerant			Kang W, Bao J, Zheng J, Xu F, Wang L. Phytoremediation of heavy metal contaminated soil potential by woody plants on Tonglushan ancient Cu spoil heap in China. Int J Phytoremediation. 2018;20(1):1-7. doi:10.1080/15226514.2014.950412
Degradation	4–8	Europe, Asia	Cook and Hesterberg, 2012 Karthikeyen et al., 2012 Kulakow, 2006d
Extraction	4–8	Europe, Asia	Negri and Hinchman, 2000
Accumulator			Midhat L, Ouazzani N, Esshaimi M, Ouhammou A, Mandi L. Assessment of heavy metals accumulation by spontaneous vegetation: Screening for new accumulator plant species grown in Kettara mine-Marrakech, Southern Morocco. Int J Phytoremediation. 2017;19(2):191-198. doi:10.1080/15226514.2016.1207604
Extraction	3–11	Europe Middle East	Gilbert and Crowley, 1997
Extraction	Grown as annual	USA	ITRC PHYTO 3 Olsen, 1994

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Microlaena stipoides	Weeping Grass	Petroleum	TPH	Herbaceous
Millettia reticulata	Evergreen Wisteria	Petroleum	Unspecified	Vine
Minuartia verna	Spring Sandwort	Heavy Metals	Zn	Herbaceous
Miscanthus × giganteus	Giant Maiden Grass	Petroleum	PAH	Herbaceous
Miscanthus floridulus	Giant Miscanthus	Radionuclides	Ba	Herbaceous
Miscanthus giganteus	Miscanthus	Heavy Metals	Cu, Pb, M, Cd, Zn	
Monochoria hastata	Oval-leafed pondweed	Heavy Metals	Mg, Fe, Contaminants of concern (COC)	Herbaceous
Moraea bicolor	Fortnight Lily	Petroleum	Unspecified	Shrub
Moraea iridioides (D.iridioides)	African Iris	Petroleum	Unspecified	Shrub
Morinda reticulate	Mapoon	Heavy Metals	Se	Herbaceous
Morus alba	White Mulberry	Petroleum	PAH	Tree
Morus alba "Platanifolia"	Fruitless Mulberry	Heavy Metals	Anthracene, As	
Morus rubra	Red Mulberry	Petroleum	PAH	Tree
Morus rubra	Red Mulberry	POP	PCB	Tree
Myoporum sandwicense	False Sandalwood	Petroleum	TPH PAH	Tree
Myriophyllum aquatica	Parrot Feather	Explosives	RDX TNT	Wetland
Myriophyllum aquaticum	Parrot feather	Pesticides	Demeton-8-methyl Malathion Ruelene Atrazine Trifluralin Terbutryn Cycloxidin	Wetland
Myriophyllum spicaticum	Eurasian Water Milfoil	Explosives	TNT	Wetland
Myriophyllum spicatum	Eurasian watermilfoil	Heavy Metals	As, Cd, Cu, Ni, Pb, Zn	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation	9–11	Australia	Cook and Hesterberg, 2012 Gaskin and Bentham, 2010
Tolerance	8+		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Hyperaccumulator	6–11	Europe	Reeves, 2006
Degradation	4–9	Japan	Techer et al., 2012
Extraction	5–9	East Asia	ITRC PHYTO 3 Li et al., 2011
Tolerant/Accumulator			1) (Phyto Textbook) Techer, D., Martinez-Chois, C., Laval-Gilly, P., Henry, S>, Bennasroune, A., D'Iannocenzo, M., and Falla, J. 2012. Assessment of Miscanthus× giganteus for rhizore-mediation of long term PAH contaminated soils. Applied Soil Ecology 62, 99. 42-49. 2) (Phyto Textbook) Kocon, A., and Matyka, M. 2012. Phytoextractive potential of Miscanthus giganteus and Sida hermaphrodita growing under moderate pollution of soil with Zn and Pb. Journal of Food, Agriculture and EnvFement 10 (2), pp. 1253-1256. 3) Zhang J, Yang S, Huang Y, Zhou S. The Tolerance and Accumulation of Miscanthus Sacchariflorus (maxim.) Benth., an Energy Plant Species, to Cd. Int J Phytoremediation. 2015;17(1-6):538-545. doi:10.108 0/15226514.2014.922925 4) Bang J, Kamala-Kannan S, Lee KJ, et al. Phytoremediation of Heavy Metals in Contaminated Water and Soil Using Miscanthus sp. Goedae-Uksae 1. Int J Phytoremediation. 2015;17(1-6):515-520. doi:10.1080/15226514.2013.862209
Accumulator			Hazra M, Avishek K, Pathak G. Phytoremedial Potential of Typha latifolia, Eichornia crassipes and Monochoria hastata found in Contaminated Water Bodies Across Ranchi City (India). International Journal of Phytoremediation. 2015 ;17(9):835-840. DOI: 10.1080/15226514.2014.964847.
Tolerance	8–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Tolerance	8–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Hyperaccumulator	Not available	Australia	Baker and Reeves, 2000 Knott et al., 1958
Degradation	3–9	China	Cook and Hesterberg, 2012 Euliss, 2004
N/A			1) Basel Al-Yousfi A. et al. (2000). "Phytoremediation-The Natural Pump-and-Treat and Hydraulic Barrier System." Practice Periodicals of Hazardous, Toxic, and Radioactive Waste Management, April 2000, p 73-77.
Degradation	5–10	Eastern USA	Cook and Hesterberg, 2012 Euliss, 2004 Rezek et al., 2009
Extraction	4–9	North America	Olson et al., 2003
Degradation	10–11	Hawaii	Tang et al., 2004
Degradation	6–10	South America	Bhadra et al., 2001 Hughes et al., 1997 Just and Schnoor, 2000 Just and Schnoor, 2004 Thompson et al., 1999 Wang et al., 2003
Degradation or hydraulic control	6–10	South America	Gao et al., 1998 ITRC PHYTO 3 Turgut, 2005
Degradation	6–10	Europe, Asia	Hughes et al., 1997 Thompson et. al., 1999
Hyperaccumulator			Lu G, Wang B, Zhang C, et al. Heavy metals contamination and accumulation in submerged macrophytes in an urban river in China. Int J Phytoremediation. 2018;20(8):839-846. doi:1 0.1080/15226514.2018.1438354

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Myriophyllum verticillatum	Whorl-leaf Watermilfoil	Heavy Metals	Fe, Cr, Zn, Ni, Cu	
Nandina domestica	Heavenly Bamboo	Petroleum	Unspecified	Shrub
Native Cottonwood	Native Cottonwood		Trichloroethylene (TCE) and by-products	
Native Willow	Native Willow	POP	Benzene, Pb, Hg, Ni, Polychlorinated Biphenyl (PCB), Ag, Toluene	
Nepeta cataria	Catnip	Heavy Metals	Cr, Ni, Fe, Mn, Co, Cu, Zn	
Nephrolepis exaltata	Boston Fern	Petroleum	Benzene, Formaldehyde, Toluene, Trichloroethylene (TCE) and by-products, Xylene	Herbaceous
Nephrolepis obliterata	Kimberly Queen	Petroleum	Alcohol, Benzene, Formaldehyde, Toluene, Xylene	
Neptunia amplexicaulis	Se Weed Water Mimosa	Heavy Metals	Se	Herbaceous
Nerium oleander	Oleander	Petroleum	Unspecified	Shrub
Nicotiana tabacum	Tobacco (transgenic)	Explosives	RDX TNT	Herbaceous
Nicotiana tabacum	Tobacco	Heavy Metals	Cd, Zn	Herbaceous
Noccaea caerulescens	Thlaspi alpestre	Heavy Metals	Cd, Zn	
Noccaea praecox	Early Penny Cress	Heavy Metals	Cd, Pb, Zn	
Nymphaea odorata	Water Lily	Heavy Metals	Cr, Cu, Mn	
Oenothera glazioviana	Evening Primrose	Heavy Metals	Cu	Herbaceous
Olea Europaea	Olive	Heavy Metals	Cu, Zn, Pb	
Onobrychis viciifolia	Sainfoin	Petroleum	TPH	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			Sapci Z, Ustun EB. Heavy Metal Uptakes by Myriophyllum verticillatum from Two EnvFe-mental Matrices: The Water and the Sediment. Int J Phytoremediation. 2015;17(1-6):290-297. doi:10.1080/15226514.2014.898022
Tolerance	6–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
N/A			1) Jordahl, J., R. Tossell, M. Barackman and G. Vogt (2003) Phytoremediation for Hydraulic Control and Remediation: Beale 2) Air Force Base and Koppel Stockton Terminal. Abstracts from US EPA International Applied Phytotechnologies Workshop March 3-5, 2003 Chicago, IL
N/A			1) L. A. Newman et al. Remediation of trichloroethylene in an artificial aquifer with trees: A controlled field study EnvFe. Sci. Technol. 33:2257-2285 (1999)
Accumulator			Nawab J, Khan S, Shah MT, Khan K, Huang Q, Ali R. Quantification of Heavy Metals in Mining Affected Soil and Their Bioaccumulation in Native Plant Species. Int J Phytoremediation. 2015;17(9):801-813. doi:10.1080/15226514.2014.981246
Hyperaccumulator			1) B.C Wolverton and John D. Wolverton. Wolverton EnvFemental Services. http://www.wolvertonenvFemental.com/MsAcad-93.pdf
Accumulator, Hyperaccumu-lator			1) Plants "Clean" Air Inside Our Homes (kilde NASA) 2) Wolverton, B.C. (1996) How to Grow Fresh Air. New York: Penguin Books. 3) B. C. Wolverton and J.D. Wolverton. "Plants and Soil Microorganisms: Removal of Formaldehyde, Xylene, Ammonia From the Indoor EnvFement". Retrieved 2011-08-27.
Hyperaccumulator	Not available	Australia	Baker and Reeves, 2000 McCray and Hurwood, 1963
Tolerance	9–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Degradation	Grown as annual	North America	French et al., 1999 Hannink et al., 2001 Pieper and Reineke, 2000 Rosser et al., 2001 Van Aken et al., 2004
Accumulator	Grown as annual	North America	ITRC PHYTO 3 Kumar et al., 1995 Vasiliadou and Dordas, 2010 Yancey et al., 1998
Accumulator, Hyperaccumu-lator			1) Broadhurst CL, Chaney RL, Davis AP, et al. Growth and Cd Phytoextraction by Swiss Chard, Maize, Rice, Noccaea caerulescens, and Alyssum murale in Ph Adjusted Biosolids Amended Soils. Int J Phytoremediation. 2015;17(1-6):25-39. doi:10.1080/15226514.2013.828017 2) Simmons RW, Chaney RL, Angle JS, et al. Towards practical Cd phytoextraction with Noccaea caerulescens. Int J Phytoremediation. 2015;17(1-6):191-199. doi:10.1080/15226514.2013.876961
Hyperaccumulator			Tlustoš P, B?endová K, Száková J, Najmanová J, Koubová K. The long-term variation of Cd and Zn hyperaccumulation by Noccaea spp and Arabidopsis halleri plants in both pot and field conditions. Int J Phytoremediation. 2016;18(2):110-115. doi:10.1080/15226514.2014.981243
Accumulator of Cu and Mn.			1) http://ourgardengang.tripod.com/whsuckitup.htm
Excluder	3–8	North America	Guo et al., 2013
Accumulator			Nirola R, Megharaj M, Aryal R, Naidu R. Screening of metal uptake by plant colonizers growing on abandoned Cu mine in Kapunda, South Australia. Int J Phytoremediation. 2016;18(4):399-405. doi:10.1080/15226514.2015.1109599
Degradation	3–10	Europe	Cook and Hesterberg, 2012 Muratova et al., 2008

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Opuntia ficus	Pirckly Pear	Petroleum	Pb, Total petroleum hydro-carbons	
Oryza sativa	Rice	Explosives	TNT	Herbaceous
Oryza sativa	Rice	Pesticides	Benthiocarb Parathion Propanil Atrazine Lambda-cyhalothrin Diazinon Fipronil	Wetland
Oryza sativa	Asian Rice	Heavy Metals	As	Herbaceous
Oryza sativa L	Rice	Heavy Metals	Cd, heavy metals	Herbaceous
Osmanthus fragrans	Sweet Osmanthus	Heavy Metals	Cd	Herbaceous
Panicum coloratum	Klinegrass	Petroleum	PAH	Herbaceous
Panicum repens	Torpedo grass	Heavy Metals	Cd, Pb	Herbaceous
Panicum virgatum	Switchgrass	Petroleum	Anthracene PAH (total priority) Pyrene TPH PAH	Herbaceous
Panicum virgatum	Switchgrass	Explosives	RDX	Herbaceous
Panicum virgatum	Switchgrass	Heavy Metals	Pb, Cd	Herbaceous
Panicum virgatum	Blue Switchgrass	Petroleum	Atrazine	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			Escobar-Alvarado LF, Vaca-Mier M, López-Callejas R, Rojas-Valencia MN. Efficiency of Opuntia ficus in the phytoremediation of a soil contaminated with used motor oil and Pb, compared to that of Lolium perenne and Aloe barbadensis. Int J Phytoremediation. 2018;20(2):184-189. doi:10.1080/15226514.2017.1365332
Degradation	Grown as annual	East Asia	Vila et al., 2007a Vila et al., 2007b Vila et al., 2008
Degradation or hydraulic control	Grown as annual	East Asia	Anderson et al., 1993 Hoagland et al., 1994 ITRC PHYTO 3 Moore and Kroeger, 2010 Reddy and Sethunathan, 1983
Potential Accumulators	2–11	Indonesia, Southeast Asia	Molla et al., 2010
Hyperaccumulator			1) (Phyto Textbook) Mandal, A., Purakayastha, T., Patra, A., and Sanyal, S. 2012. Phytoremediation of As contaminated soil by Pteris vittata L. II. Effect on As uptake and rice yield. International Journal of Phytoremediation 14 (6) pp. 621-628. 2) Zhou L, Wu L, Li Z, et al. Influence of Rapeseed Cake on Heavy Metal Uptake by a Subsequent Rice Crop After Phytoextraction Using Sedum plumbiZnicola. Int J Phytoremediation. 2015;17(1-6):76-84. doi:10.1080/15226514.2013.837026
Accumulator/Tolerant			1) Kang W, Bao J, Zheng J, Xu F, Wang L. Phytoremediation of heavy metal contaminated soil potential by woody plants on Tonglushan ancient Cu spoil heap in China. Int J Phytoremediation. 2018;20(1):1-7. doi:10.1080/15226514.2014.950412 2) Zeng P, Guo Z, Cao X, Xiao X, Liu Y, Shi L. Phytostabilization potential of ornamental plants grown in soil contaminated with Cd. Int J Phytoremediation. 2018;20(4):311-320. doi:10.1080/15226514.2017.1381939
Degradation	10–12	Africa	Balcom and Crowley, 2009 Olson et al., 2007 Qiu et al., 1994, 1997
Tolerant			Gao G, Zeng X, Li Z, Chen A, Yang Z. Variations in several morphological characteristics and Cd/Pb accumulation capacities among different ecotypes of torpedograss responding to Cd-Pb stresses. Int J Phytoremediation. 2017;19(9):844-861. doi:10.1080/15226514.2017.1284759
Degradation	2–9	North America	Aprill and Sims, 1990 Cook and Hesterberg, 2012 Euliss et al., 2008 Kulakow, 2006d Pradhan et al., 1998 Reilley et al., 1996 Reilley et al., 1993 Schwab and Banks, 1994 Wilste et al., 1998
Degradation	2–9	North America	Brentner et al., 2010
Hyperaccumulator	2–10	North America	1) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 2) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf 4) USDA NRCS Plant Materials Center, Manhattan, Kansas & Kansas State University, Forestry Researchhttp://plants.usda.gov/factsheet/pdf/fs_sani.pdf (Source for Ni, PAH, and Ag) 5) (Phyto Textbook) Albright III, V., and Coats, J. 2014. Disposition of atrazine metabolites following uptake and degradation of atrazine in Switchgrass. International Journal of Phytoremediation 16 (1), pp. 62-72, DOI, 10.1080/15226514.2012.759528. 6) Mcintosh, Patrick, et al. "Breakdown of Low-Level Total Petroleum Hydrocarbons (TPH)
Accumulator	2–11	North America	1) http://www.big-grass.com/Panicum%20virgatum.html

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Panicum virgatum Panicum virgatum 'Alamo'	Switchgrass	Radionuclides	90Sr, 137Cs	Herbaceous
Panicum virgatum(9) Panicum virgatum var. Pathfinder (10)	Switchgrass	Pesticides	Atrazine Pendimethalin	Herbaceous
Parkinsonia aculeata	Jerusalem thorn	Other	Salinity	Herbaceous
Parthenocissus quinquefolia	Virginia Creeper	Radionuclides	Sr	Herbaceous
Pascopyrum smithii	Western Wheatgrass	Petroleum	Atrazine, Hydrocarbons, Pb, Polycyclic Aromatic Hydrocarbon (PAH), Zn	Herbaceous
Pascopyrum smithii (syn. Agropyron smithii)	Western Wheatgrass	Petroleum	TPH PAH	Herbaceous
Paspalum notatum	Bahia Grass	Chlorinated Sol-vents	TCE	Herbaceous
Paspalum scrobiculatum	Kodo millet	Petroleum	Petroleum hydrocarbons	Herbaceous
Paspalum vaginatum	Seashrore paspalum	Petroleum	Petroleum hydrocarbons	Herbaceous
Paulownia tomentosa	Empress Tree Princess Tree	Petroleum	PAH	Tree
Pearsonia metallifera	Pearsonia	Heavy Metals	Ni	Herbaceous
Pelargonium graveolens	Rose scented geranium	Heavy Metals	Cd, Ni, Cr, Pb	Herbaceous
Pelargonium roseum	Scented Geranium	Heavy Metals	Cd, Ni	Herbaceous
Peltophorum pterocarpum	Cupod	Heavy Metals	Pb	Herbaceous
Pennisetum glaucum	Millet	Petroleum	TPH	Herbaceous
Pennisetum purpureum Schum.	Elephantgrass	Inorganic	excess soil Ph	Herbaceous
Petroselinum crispum	Parsley	Inorganic	Hg	Herbaceous
Phalaris arundinacea	Reed Canary Grass	Petroleum	PAH	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Extraction	2–9	USA	Entry et al., 1996 Entry and Watrud, 1998 ITRC PHYTO 3
Degradation or hydraulic control	2–9	North America	Albright and Coats, 2014 Burken and Schnoor, 1997 Henderson et al., 2006 Murphy and Coats, 2011
Accumulator			Devi S, Nandwal AS, Angrish R, Arya SS, Kumar N, Sharma SK. Phytoremediation potential of some halophytic species for soil salinity. Int J Phytoremediation. 2016;18(7):693-696. doi:10.1080/15226514.2015.1131229
Extraction	3–10	Eastern USA	Li et al., 2011
N/A			1) USDA NRCS Plant Materials Center, Manhattan, Kansas & Kansas State University, Forestry Researchhttp://plants.usda.gov/factsheet/pdf/fs_sani.pdf - Ni, pah, Ag 2) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 3) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Degradation	4–9	North America	Aprill and Sims, 1990 Cook and Hesterberg, 2012 Karthikeyen et al., 2012 Kulakow, 2006d Olson et al., 2007
Degradation	7–10	Central and South America	Anderson and Walton, 1992 ITRC PHYTO 3
Accumulator/Tolerant			Anyasi RO, Atagana HI. Profiling of plants at petroleum contaminated site for phytoremediation. Int J Phytoremediation. 2018;20(4):352-361. doi:10.1080/15226514.2017.1393386
Accumulator/Tolerant			Anyasi RO, Atagana HI. Profiling of plants at petroleum contaminated site for phytoremediation. Int J Phytoremediation. 2018;20(4):352-361. doi:10.1080/15226514.2017.1393386
Degradation	7–10	China	Macci et al., 2012
Hyperaccumulator	Not available	Zimbabwe	Wild, 1970 Brooks and Yang, 1984
Hyperaccumulator			Chand S, Singh G, Patra DD. Performance of rose scented geranium (Pelargonium graveolens) in heavy metal polluted soil vis-à-vis phytoaccumulation of metals. Int J Phytoremediation. 2016;18(8):754-760. doi:10.1080/15226514.2015.1131236
Accumulator	10–11	South Africa	Mahdieh et al., 2013
Accumulator			(Phyto Textbook) Meeinkuirt, W., Pokethitiyook, P., Kruatrachue, M., Tanhan, P., and Chairyarat, R. 2012. Phytostabilization of a Pb-contaminated mine tailing by various tree species in pot and field trial experiments. International Journal of Phytoremediation 14 (9), pp. 925-938.
Degradation	Grown as annual	Africa, Asia	Cook and Hesterberg, 2012 Muratova et al., 2008
			(Phyto Textbook) Silveira, M. L., Vendramini, J. M. B., Sui, X., Sollenberger, L., and O'Connor, G. A. 2013. Screening perennial warm-season bioenergy crops as an alternative for phytoremediation of excess soil P. Bioenergy Reserach 6 (2) pp. 469-475.
Accumulator			Bibi A, Farooq U, Naz S, et al. Phytoextraction of HG by parsley (Petroselinum crispum) and its growth responses. Int J Phytoremediation. 2016;18(4):354-357. doi:10.1080/15226514.2015.1109590
Degradation	4–9	Europe	McCutcheon and Schnoor, 2003

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Phalaris arundinacea	Reed Canary Grass	Explosives	RDX TNT	Herbaceous
Phanerochaete chrysosporium	White Rot Fungi		Trichloroethylene (TCE) and by-products	
Phapis excelsa	Lady Palm	Other	Carbon Monoxide, Formal-dehyde	
Phaseolaris vulgaris	Pole Bean	POP	p,p'-DDE (Weathered DDT)	Herbaceous
Phaseolus coccineus cv. Half White Runner	Bean	Radionuclides	238U	Herbaceous
Phaseolus vulgaris	Bush Bean	Explosives	TNT	Shrub
Phaseolus vulgaris	Bush bean	Pesticides	Diazinon Parathion Temik	Shrub
Phaseolus vulgaris cv. Buenos Aires	Bean	Heavy Metals	As	Herbaceous
Philodendron scandens	Heart-Leaf Philodendron		Formaldehyde	Herbaceous
Phleum pratense	Common Timothy Grass	Radionuclides	90Sr, 137Cs	Herbaceous
Phoenix roebelenii	Dwarf Date Palm	Petroleum	Benzene, Cd, Carbon Mon-oxide, Cr, Formaldehyde, Pb, Xylene	
Phormium tenax	New Zealand Flax	Petroleum	Unspecified	Shrub
Photinia fraseri	Red Tip Photinia	Petroleum	Unspecified	Shrub
Phragmites australis	Common Reed	Petroleum	Benzene Biphenyl Ethylb-enzene Toluene p-Xylene TPH MTBE	Wetland
Phragmites australis	Common Reed	Chlorinated Sol-vents	Bromoform Chlorobenzene Chloroform Dichlo-roethane PCE TCE	Herbaceous
Phragmites australis	Common Reed	Explosives	TNT	Herbaceous
Phragmites australis	Phragmites	Radionuclides	Th, U, 137Cs	Herbaceous
Phragmites karka	Perennial grass	Heavy Metals	As	Herbaceous
Phyllanthus serpentinus	Phyllanthus	Heavy Metals	Ni	Not available
Phyllomeli coronata	Phyllanthus	Heavy Metals	Ni	Not available
phyto	Legumes	Petroleum	TPH PAH	Varies

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation	4–9	Europe	Best et al., 1997 Best et al., 1999 Kiker and Larson, 2001 Thompson et. al., 1999 Just and Schnoor, 2004
N/A			1) Koehler, H., J. Warrelmann, T. Frische, P. Behrend, and U. Walter. (2002) In-Situ Phytoremediation of TNT- Contaminated Soil. Acta Biotechnologia 22:1-2, 67-80.
Accumulator			1) B.C Wolverton and John D. Wolverton. Wolverton EnvFemental Services. http://www.wolvertonenvFemental.com/MsAcad-93.pdf
Extraction	Grown as annual	Central America	White, 2000
Extraction	Grown as annual	Southern USA	Dushenkov et al., 1997b ITRC PHYTO 3
Degradation	Grown as annual	Central America	Cataldo et al., 1989 Thompson et. al., 1999
Degradation or hydraulic control	Grown as annual	Central America	Anderson et al., 1993 Hsu and Bartha, 1979 ITRC PHYTO 3
Potential Accumulators	Grown as annual	Central America	Carbonell-Barrachina et al., 1997 ITRC PHYTO 3
N/A			1) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University. http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm
Extraction	5+	Europe, Asia	ITRC PHYTO 3 Vasudev et al., 1996
Hyperaccumulator			1) B. C. Wolverton and J.D. Wolverton. "Plants and Soil Microorganisms: Removal of Formaldehyde, Xylene, Ammonia From the Indoor EnvFement". Retrieved 2011-08-27.
Tolerance	8–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Tolerance	7–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Degradation	4–10	Europe, Asia	Anderson et al., 1993 Reiche and Borsdorf, 2010 Ribeiro et al., 2013 Unterbrunner et al., 2007
Degradation	4–10	Europe, Asia	Anderson et al., 1993 ITRC PHYTO 3
Degradation	4–10	Europe, Asia	Nepovim et al., 2005 Vanek et al., 2006
Extraction	4–10	Europe, Asia	Li et al., 2011 Soudek et al., 2004
Accumulator			1) Badejo AA, Sridhar MK, Coker AO, Ndambuki JM, Kupolati WK. Phytoremediation of Water Using Phragmites karka and Veteveria nigritana in Constructed Wetland. Int J Phytoremediation. 2015;17(9):847-852. doi:10.1080/15226514.2014.964849 2) Raj A, Jamil S, Srivastava PK, Tripathi RD, Sharma YK, Singh N. Feasibility Study of Phragmites karka and Christella dentata Grown in West Bengal as As Accumulator. Int J Phytoremediation. 2015;17(9):869-878. doi:10.1080/15226514.2014.964845
Hyperaccumulator	Not available	New Caledonia	Kersten, 1979
Hyperaccumulator	Not available	Caribbean	Reeves et al., 2006
Degradation	Varies	Worldwide	Cook and Hesterberg, 2012 Kulakow, 2006a Kulakow, 2006b Kulakow, 2006e Liu et al., 2010 Tsao, 2006a Tsao, 2006b

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Phytolacca acinosa Roxb. w/ Arthrobacter echigonensis MN 1405	Indian pokeweed	Heavy Metals	Mn	Herbaceous
Phytolacca americana	Pokeweed	Heavy Metals	Rare Earth Element	Herbaceous
Picea glauca var. densata	Black Hills Spruce	Petroleum	BTEX	Tree
Picea mariana	Black Spruce	Radionuclides	U	Tree
Picea pungens	Dwarf Globe Blue Spruce	Petroleum	Unspecified	Shrub
Pinus banksiana	Jack Pine	Petroleum	BTEX	Tree
Pinus mugo	Mugo Pine	Other	Particulate matter	Tree
Pinus mugo pumilo	Dwarf Mugo Pine	Petroleum	Unspecified	Shrub
Pinus nigra	Austrian Pine	POP	PCB	Tree
Pinus nigra	Austrian Pine	POP	PCB	Tree
Pinus palustris	Longleaf Pine	Chlorinated Sol-vents	TCE	Tree
Pinus ponderosa	Ponderosa Pine	Pesticides	Atrazine	Tree
Pinus ponderosa	Ponderosa Pine	Radionuclides	Plutonium, Sr	Tree
Pinus ponderosa Dougl. ex Laws	Ponderosa Pine	Radionuclides	137Cs, 90Sr	Tree
Pinus radiata	Monterey Pine	Heavy Metals	Cs, Sr, T, U	Tree
Pinus radiata D Don	Monterey Pine	Radionuclides	137Cs, 90Sr	Tree
Pinus spp.	Conifers	Petroleum	MTBE TBA (Tert-butyl Alcohol)	Tree
Pinus sylvestris	Scots Pine	Petroleum	TPH	Tree
Pinus taeda	Loblolly Pine	Petroleum	Dioxene, BTEX, TPH	Tree
Pinus taeda	Loblolly pine	Chlorinated Sol-vents	TCE 1,4 dioxene	Tree
Pinus thunburgii	Japanese Pine	Petroleum	Dioxene	Tree
Pinus virginiana	Virginia Pine	Petroleum	Dioxene	Tree
Pistacia chinensis	Chinese Pistachio	Petroleum	Unspecified	Tree

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Hyperaccumulator			Li, Fengyu, et al. "Phytolacca AcinosaRoxb. WithArthrobacter echigonensisMN1405 Enhances Heavy Metal Phytoremediation." International Journal of Phytoremediation, vol. 18, no. 10, 2016, pp. 956–965., doi:10.1080/15226514.2016.1183573.
Accumulator			Yuan M, Liu C, Liu WS, et al. Accumulation and fractionation of rare earth elements (REEs) in the naturally grown Phytolacca americana L. in southern China. Int J Phytoremediation. 2018;20(5):415-423. doi:10.1080/15226514.2017.1365336
Degradation	2–6	North Dakota	Cook and Hesterberg, 2012 Fagiolo and Ferro, 2004
Extraction	3–6	North America	Baumgartner et al., 1996
Tolerance	2–8		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Degradation	3–8	North America	Cook and Hesterberg, 2012 Fagiolo and Ferro, 2004
Accumulator			(Phyto Textbook) Saebo, A., Popek, R., Nawrot, B., Hanslin, H., Gawronska, H. and Gawronski, S. 2013. Plant species differences in particulate matter accumulation on leaf surfaces. Science of the Total Envrionment 427, pp. 347-354.
Tolerance	2–8		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Extraction	5+	Europe	Leigh et al., 2006
N/A	5+	Europe	1) Leigh, M.B., J. Fletcher, D.P. Nagle, P. Prouzova, M. Mackova and T. Macek (2003) Rhizoremediation of PCBS: Mechanistic and Field Investigations
Degradation	7–10	Southeastern USA	Strycharz and Newman, 2009a
Degradation or hydraulic control	3–7	North America	Burken and Schnoor, 1997
Accumulator	3–8	North America	1) http://www.ubcbotanicalgarden.org/potd/2005/06/pinus_ponderosa.php
Extraction	3–9	North America	Entry et al., 1993 ITRC PHYTO 3
Accumulator	8+	California	1) Phytoremediation of RadioÂ¬nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm
Extraction	8+	California	Entry et al., 1993 ITRC PHYTO 3
Degradation	Varies	Worldwide	Arnold et al., 2007
Degradation	3–8	Europe, Asia	Cook and Hesterberg, 2012 Palmroth et al., 2006
Degradation	6–9	North America	Ferro et al., 2013 Guthrie Nichols et al., 2014
Degradation	6–9	Southeastern USA	Anderson and Walton, 1991, 1992, 1995 ITRC PHYTO 3 Stanhope et al., 2008 Strycharz and Newman, 2009a
Degradation	5–10	Japan	Ferro et al., 2013
Degradation	5–8	North America	Ferro et al., 2013
Tolerance	6–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Pistia stratiotes	Water Lettuce	Heavy Metals	Fe, Mn, Cr, Pb, Cu	Herbaceous
Pisum sativum	Peas	Pesticides	Diazinon	Herbaceous
Pisum sativum	Peas	Radionuclides	137Cs, 106Ru, 99Tc, 144Ce	Herbaceous
Pittosporum tobira	Pittosporum	Petroleum	Unspecified	Shrub
Pityrogramma calomelanos	Dixie Agback Fern	Heavy Metals	Cr, Cu, Pb, Hg	Herbaceous
Planchonella oxyhedra		Heavy Metals	Ni	
Plantago major	Broadleaf Plantain	Pesticides	Imidacloprid	Herbaceous
Plantanus occidentalis	Sycamore	Chlorinated Sol-vents	TCE	Tree
Platanus x acerfolia	Norway Maple	Heavy Metals	Pb	Tree
Platycladus orientalis	Oriental Arborvitae	Heavy Metals	Cd	Tree
Poa pratensis	Kentucky Bluegrass	Petroleum	TPH PAH	Herbaceous
Poa spp.	Common meadow grasses	Radionuclides	134Cs	Herbaceous
Poaceae	Grasses	Petroleum	TPH PAH BTEX	Herbaceous
Podranea riscasoliana	Pink Trumpet Vine	Petroleum	Unspecified	Vine
Polycarpaea synandra	Polycarpaea	Heavy Metals	Zn	Herbaceous
Polygonum hydropiper	Water Pepper	Inorganic	P	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			1) http://www.ncbi.nlm.nih.gov/pubmed/19104863 2) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20 species%20phyto.pdf 3) Victor KK, Séka Y, Norbert KK, Sanogo TA, Celestin AB. Phytoremediation of wastewater toxicity using water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes). Int J Phytoremediation. 2016;18(10):949-955. doi:10.1080/15226514.2016.1183567 4) Galal TM, Eid EM, Dakhil MA, Hassan LM. Bioaccumulation and rhizofiltration potential of Pistia stratiotes L. for mitigating water pollution in the Egyptian wetlands. Int J Phytoremediation. 2018;20(5):440-447. doi:10.1080/15226514.2017.1365343
Degradation or hydraulic control	Grown as annual	Europe, Asia	Anderson, Guthrie and Walton, 1993 ITRC PHYTO 3
Extraction	Grown as annual	Europe, Asia	Bell et al., 1988 ITRC PHYTO 3 Vasudev et al., 1996
Tolerance	8–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
N/A			1) Fryer, Janet L. 2011. Microstegium vimineum. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2011, December 7].
Hyperaccumulator			Hamdan AM, Bijaksana S, Tjoa A, Dahrin D, Kirana KH. Magnetic characterizations of Ni hyperaccumulating plants (Planchonella oxyhedra and Rinorea bengalensis) from Halmahera, Indonesia. Int J Phytoremediation. 2019;21(4):364-371. doi:10.1080/15226514.2018.1524839
Degradation or hydraulic control	3+	Europe, Asia	Romeh, 2009
Degradation	4–9	Eastern USA	Strycharz and Newman, 2009b, 2010
Accumulator/Tolerant			Kang W, Bao J, Zheng J, Xu F, Wang L. Phytoremediation of heavy metal contaminated soil potential by woody plants on Tonglushan ancient Cu spoil heap in China. Int J Phytoremediation. 2018;20(1):1-7. doi:10.1080/15226514.2014.950412
Tolerant			Zeng P, Guo Z, Xiao X, Cao X, Peng C. Response to Cd and phytostabilization potential of Platycladus orientalis in contaminated soil. Int J Phytoremediation. 2018;20(13):1337-1345. doi:10.1080/15226514.2018.1501338
Degradation	3–8	Europe	Kulakow, 2006c Palmroth et al., 2006
Extraction	varies	varies	ITRC PHYTO 3 Salt et al., 1992
Degradation	Varies	Worldwide	Luce, 2006 Tossell, 2006
Tolerance	9+		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Hyperaccumulator	Not available	Western Australia	Reeves, 2006
Accumulator			Ye D, Li T, Zheng Z, Zhang X, Yu H. P uptake characteristics and root morphological responses in the mining ecotype of Polygonum hydropiper under high organic P media. Int J Phytoremediation. 2018;20(6):608-615. doi:10.1080/15226514.2017.1413327

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Polygonum lapathifolium	Smartweed	Heavy Metals	Cr, Cu, Pb	Herbaceous
Polygonum persicaria	Spotted Lady's Thumb	POP	PCB	Herbaceous
Polygonum punctatum	Smartweed	Explosives	RDX	Herbaceous
Poplulus trichocarpa x P. deltoides	Hybrid Poplar	Petroleum	Gasoline, Diesel, Jet Fuel, (petroleum hydrocarbon); benzene, toluene, ethylb-enzene, and xylenes	
Populus alba	White Poplar	Heavy Metals	As, Pb, Cu, Mn, Zn	
Populus alba Populus spp.	Poplar species and hybrids	Heavy Metals	As	Tree
Populus deltoides	Eastern Cottonwood	Heavy Metals	As	
Populus deltoides × nigra DN34 (24, 25) Populus tremula × tremuloides var. Etropole (26)	Populus spp. and hybrids	Explosives	RDX TNT	Tree
Populus deltoides ssp. Monilifera	Plains Cottonwood	Petroleum	Benzene, Polycyclic Aro-matic Hydrocarbon (PAH)	
Populus euphratica (with Phyllobacterium sp.)	Euphrates poplar	Heavy Metals	Zn, Cu, Ni, Pb	
Populus grandidentata	Largetooth Aspen	Radionuclides	226Ra	Tree

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Hyperaccumulator			1) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm 2) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf 4) http://www.missouriplants.com/Whitealt/Polygonum_hydropÂ¬iperoides_page.html 5) USDA NRCS Plant Materials Center, Manhattan, Kansas & Kansas State University, Forestry Researchhttp://plants.usda.gov/factsheet/pdf/fs_sani.pdf 6) Liu K, Yu F, Chen M, et al. A newly found Mn hyperaccumulator--Polygonum lapathifolium Linn. Int J Phytoremediation. 2016;18(4):348-353. doi:10.1080/15226514.2015.1109589
Extraction	4–8	Eurasia	Ficko et al., 2010
Degradation	3+	North America	Kiker and Larson, 2001
Accumulator			1) Interstate Technologoy and Regulation Cooperation Work Group. Phytoremediation Decision Tree, ITRC. http://www.itrcweb.org/documents/phyto-1.pdf 2) McLinn, E., Vondracek, J., and E. Aitchison. 2001. â€œMonitoring Remediation with Trembling Leaves: Assessing the Effectiveness of a Full-Scale Phytoremediation Systemâ€ . In: A. Leeson, E. Foote, M. Banks, and V. Magar (eds.) Phytoremediation, Wetlands, and Sediments, p121-127. Battelle Press, Columbus, Ohio. 3) Negri, M.C., et al 2003 Root Development and Rooting at Depths, in S.C. McCutcheon and J.L. Schnoor, eds., Phytoremediation: Transformation and Control of Contaminants: Hoboken, NJ, John Wiley & Sons, Inc. p233-262, 912-913 Quinn, J.J., et al 200 Predicting the Effect of Deep-Rooted Hybrid Poplars on the Groundwater Flow System at a Phytoremediation Site: International Journal of Phytoremediation, vol. 3, no. 1, p. 41-60 4) (Phyto Textbook) Guthrie Nichols, E., Cook, R. L., Landmeyer, J.E., Atkinson, B., Malone, D. R., Shaw,
Accumulator			(Phyto Textbook) Madejon, P., Ciadamidaro, L., Maranon, T., and Murillo, J.M. 2012. Long-term biomonitoring of soil contamination using poplar trees: accumulation of trace elements in leaves and fruits. International Journal of Phytoremediation 15, pp. 602-614.
Potential Accumulators	2–9	varies	Ciurli et al., 2013 Madejón et al., 2012
Tolerant, Hyperaccumulator			1) U.S EnvFemental Protection Agency (EPA). Phytoremediation field studies database for chlorinated solvents, pesticides, explosives, and metals. http://www.afcee.af.mil/shared/media/document/AFD-071130-018.pdf3) Hussain S, Akram M, Abbas G, et al. As tolerance and phytoremediation potential of Conocarpus erectus L. and Populus deltoides L. Int J Phytoremediation. 2017;19(11):985-991. doi:10.1080/15226514.2017.1303815 4) (Phyto Textbook) Ciurli, A., Lenzi, L., Alpi, A., and Pardossi, A. 2014. As uptake and translocation by plants in pot and field experiments. International Journal of Phytoremediation 16 (7-8), Special Issue: The 9th Interational Phytotechnology Society Conference -- Hasselt, Belgium 2012, pp. 804-823, DOI, 10.1080/15226514.2013.856850.
Degradation	varies	varies	Brentner et al., 2010 Thompson, 1997 Van Dillewijin et al., 2008 Van Akenet al., 2004
N/A			1) United States, E. P. (2005). Road Map to Understanding Innovative Technology Options for Brownfieldâ€™s Investigation and Cleanup. (Fourth ed.). Washington, DC: U.S. EnvFemental Protection Agency, Office of Solid Waste and Emergency ReÂ¬sponse, Office of Superfund Remediation and Technology Innovation.
Accumulator			Zhu D, Ouyang L, Xu Z, Zhang L. Rhizobacteria of Populus euphratica Promoting Plant Growth Against Heavy Metals. Int J Phytoremediation. 2015;17(10):973-980. doi:10.1080/15226514.2014.981242
Extraction	3–9	Northeastern USA	Clulow et al., 1992 ITRC PHYTO 3

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Populus maximowiczii	Japanese Poplar	Petroleum	Benzene, Ethyl, Perchloro-ethylene (PCE), Toluene, Trichloroethylene (TCE) and by-products, Vinyl Chloride, Xylene	
Populus monviso	Poplar	Heavy Metals	Cd, Cu, Ni, Zn	
Populus nigra (var.italica)	Black Polar	Heavy Metals	Heavy Metals and Hydro-carbons	
Populus nigra L.	Black poplar	Heavy Metals	Histidine, Ni	
Populus nigra var. italica	Black Poplar Lombardy Poplar	Petroleum	PAH	Tree
Populus simonii	Poplar	Radionuclides	137Cs	Tree
Populus spp. Populus deltoides Populus deltoides × Populus nigra Populus deltoides × nigra DN34 Populus trichocarpa × deltoides 'Hoogvorst' Populus trichocarpa × deltoides 'Hazendans'	Poplar species and hybrids	Petroleum	Aniline Benzene Ethylbenzene Phenol Toluene m-Xylene PAH BTEX MTBE DRO TPH	Tree
Populus spp. Populus deltoides Populus deltoides × nigra DN34 Populus trichocarpa × P. deltoides 50–189 Populus trichocarpa × P. maximowiczii 289–19	Poplar species and hybrids	Chlorinated Solvents	PCE TCE Pentachlorophenol 1,2,4-Trichlorobenzene Carbon tetrachloride 1,4 Dioxane	Tree
Populus spp. Populus alba L. var. pyramidalis	Hybrid poplar	Heavy Metals	Zn, Cd	Tree

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
N/A			1) McLinn, E., Vondracek, J., and E. Aitchison. 2001. "Monitoring Remediation with Trembling Leaves: Assessing the Effectiveness of a Full-Scale Phytoremediation System" . In: A. Leeson, E. Foote, M. Banks, and V. Magar (eds.) Phytoremediation, Wetlands, and Sediments, p121-127. Battelle Press, Columbus, Ohio.
Accumulator			1) (Phyto Textbook) Evangelou, M.W., Robinson, B.H., Gunthardt-Goerg, M.S., and Schlin, R. 2013. Metal uptake and allocation in trees grown on contaminated land: implications for biomass production. International Journal of Phytoremediation 15 (1), pp. 77-90. 2) (Phyto Textbook) Ferro, A.M., Adham, T., Berra, B., and Tsao, D. 2013. Performance of deep-rooted phreatophytic trees at a site containing total petroleum hydrocarbons. International Journal of Phytoremediation 15 (3), pp. 232-244. 3) (Phyto Textbook) Lee, K. Y., and Doty, S. L. 2012. Phytoremediation of chlorpyrifos by Populus and Salix. International Journal of Phytoremediation 14 (1), pp. 48-61. 4) (Phyto Textbook) Algreen, M., Trapp, S., and Rein, A. 2013. Phytoscreening and phytoextraction of heavy metals at Danish polluted sites using willow and poplar trees. EnvFemental Science and Pollution Research, epub. ahead of print, DOI, 10.1007/s11356-013-2085-z.
Accumulator			(Phyto Textbook) Macci, C., Doni, S., Peruzzi, E., Bardella, S., Filippis, G., Ceccanti, B., and Masciandaro, G. 2012. A real-scale soil phytoremediation. Biodegredation 24 (4) pp. 521-538
Accumulator, Hyperaccumulator			1) Ozen SA, Yaman M. Examination of correlation between histidine and Ni absorption by Morus L., Robinia pseudoacacia L. and Populus nigra L. using HPLC-MS and ICP-MS. Int J Phytoremediation. 2016;18(8):794-800. doi:10.1080/15226514.2015.1131243 2) Kacálková L, Tlustoš P, Száková J. Phytoextraction of risk elements by willow and poplar trees. Int J Phytoremediation. 2015;17(1-6):414-421. doi:10.1080/15226514.2014.910171
Degradation	4–9	Italy	Macci et al., 2012
Extraction	2–6	Northeast Asia	Soudek et al., 2004
Degradation	varies	varies	Applied Natural Sciences, Inc., 1997 Barac et al., 2009 Burken and Schnoor, 1997a Coltrain, 2004 Cook et al., 2010 Cook and Hesterberg, 2012 El-Gendy et al., 2009 Euliss et al., 2008 Euliss, 2004 Fagiolo and Ferro, 2004 Ferro et al., 2013 Ferro, 2006 ITRC PHYTO 3 Kulakow, 2006b Kulakow, 2006 Luce, 2006 Ma et al., 2004 Olderbak and Erickson, 2004 Palmroth et al., 2006 Spriggs et al., 2005 Tossell, 2006 Unterbrunner et al., 2007 Weishaar et al., 2009 Widdowson et al., 2005
Degradation	varies	varies	Burken and Schnoor, 1997 Gordon et al., 1997 Harvey, 1998 ITRC PHYTO 3 Jones et al., 1999 Miller et al., 2011 Newman et al., 1997a, 1997b Ferro et al., 2013 Orchard et al., 1998 Strycharz and Newman, 2009b, 2010 Wang et al., 1999
Accumulator	3–9	varies	Hu et al., 2013 Ruttens et al., 2011 Van Slycken et al., 2013 Thewys et al., 2010 Witters et al., 2012 Hinchman et al., 1997 ITRC PHYTO 3

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Populus spp. Populus deltoides × nigra DN34 Populus spp. ' Imperial Carolina' Populus deltoides I-69/55	Poplar Species and Hybrids	Pesticides	Alachlor Dinoseb Atrazine Dioxane Metolachlor Metribuzin Chlorpyrifos	Tree
Populus tremuloides	Trembling Aspen	Radionuclides	226Ra	Tree
Populus x Canadensis "Northeastern	Northeastern Poplar	Chlorinated Sol-vents	Trichloroethylene (TCE) and by-products	
Populus x canadensis "Orion"	Canadian Poplar, Carolina Poplar	Heavy Metals	As	
Populus X canadensis moench	"Imperial Carolina" Poplar (DN-34)	Petroleum	Benzene, Bifenthrin, TOXIN Perchloroethylene (PCE), Picloram, Toluene, Trichloroethylene (TCE) and by-products, Vinyl Chloride, Xylene	
Portulaca grandiflora	Portulaca grandiflora	Heavy Metals	Al, Cu, Fe, Zn	
Portulaca oleracea	Common Purslane, Portulaca	Heavy Metals	Cu, Na chloride, Cd, Salinity	
Potamogeton crispus	Curly pondweed	Heavy Metals	Cu, Pb	Herbaceous
Potamogeton pectinatus	Sago pondweed	Heavy Metals	As, Cd, Cu, Ni, Pb, Zn	Herbaceous
Potemogeton spp.	Pondweed	Explosives	RDX	Herbaceous
Potentilla griffithii	Potentilla	Heavy Metals	Zn, Cd	Herbaceous
Pseudomonas aeruginosa	(is a common encapsulated, Gram-negative, rod-shaped bacterium that can cause disease in plants and animals, including humans.)		Petroleum hydrocarbon, Salt	
Pseudotsuga menziesii	Douglas Fir	Heavy Metals	Cd	Tree

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation or hydraulic control	varies	varies	Applied Natural Sciences, Inc., 1997 Bin et al., 2009 Black, 1995 Burken and Schnoor, 1997b ITRC PHYTO 3 Lee et al., 2012 Nair et al., 1992 Paterson and Schnoor, 1992 Sand Creek, 2013 Schnoor et al., 1997 Schnoor, 1997
Extraction	2–8	Northern North America	Clulow et al., 1992 Dutton and Humphreys, 2005 ITRC PHYTO 3
N/A			1) Work Plan for the Phytostabilization of Chlorinated Solvents from Groundwater at Site 2, Altus Air Base, Oklahoma, NTIS: ADA381406, 1999
Hyperaccumulator			(Phyto Textbook) Ciurli, A., Lenzi, L., Alpi, A., and Pardossi, A. 2014. As uptake and translocation by plants in pot and field experiments. International Journal of Phytoremediation 16 (7-8), Special Issue: The 9th Interational Phytotechnology Society Conference -- Hasselt, Belgium 2012, pp. 804-823, DOI, 10.1080/15226514.2013.856850.
Accumulator			1) McLinn, E., Vondracek, J., and E. Aitchison. 2001. “Monitoring Remediation with Trembling Leaves: Assessing the Effectiveness of a Full-Scale Phytoremediation System” . In: A. Leeson, E. Foote, M. Banks, and V. Magar (eds.) Phytoremediation, Wetlands, and Sediments, p121-127. Battelle Press, Columbus, Ohio
Hyperaccumulator			Vijayaraghavan K, Arockiaraj J, Kamala-Kannan S. Portulaca grandiflora as green roof vegetation: Plant growth and phytoremediation experiments. Int J Phytoremediation. 2017;19(6):537-544. doi:10.1080/15226514.2016.1267699
Accumulator/Tolerant, Hyperaccumulator			1) (Phyto Textbook) Bes, C. M., Jaunatne R., and Mench M. 2013. Seed bank of Cu-contaminated topsoils at a wood preservation site: impacts of Cu and compost on seed germination. EnvFemental Monitoring and Assessment 185 (2), pp. 2039-2053. 2) Devi S, Nandwal AS, Angrish R, Arya SS, Kumar N, Sharma SK. Phytoremediation potential of some halophytic species for soil salinity. Int J Phytoremediation. 2016;18(7):693-696. doi:10.1080/1522 6514.2015.1131229 3) Lacerda, Laís Pessôa De, et al. “Salinity Reduction and Biomass Accumulation in Hydroponic Growth of Purslane (Portulaca Oleracea).” International Journal of Phytoremediation, vol. 17, no. 3, 2014, pp. 235–241., doi:10.1080/15226514.2014.88349 4. 4) Hammami, Hossein, et al. “Weeds Ability to Phytoremediate Cd-Contaminated Soil.” International Journal of Phytoremediation, vol. 18, no. 1, 2015, pp. 48–53., doi:10.1080/1522 6514.2015.1058336.
Hyperaccumulator			Lu G, Wang B, Zhang C, et al. Heavy metals contamination and accumulation in submerged macrophytes in an urban river in China. Int J Phytoremediation. 2018;20(8):839-846. doi:1 0.1080/15226514.2018.1438354
Hyperaccumulator			Lu G, Wang B, Zhang C, et al. Heavy metals contamination and accumulation in submerged macrophytes in an urban river in China. Int J Phytoremediation. 2018;20(8):839-846. doi:1 0.1080/15226514.2018.1438354
Degradation			Kiker and Larson, 2001
Accumulator	Not available	China	Qiu, 2006
Accumulator			(Phyto Textbook) Leewis, M.,-C., Reynolds, C. M., and Leigh, M. B. 2013. Long-term effects of nutrient addition and phytoremediation on diesel and crude oil contaminated soils in subarctic Alaska. Cold Regions Science and Technology, DOI, 10.1016/j.coldregions.2013.08.011.
Accumulator	5–7	North America	Astier et al., 2014

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Pteris cretica	Spider Brake Cretan Brake Fern	Heavy Metals	As	Herbaceous
Pteris cretica – Albo-Lineata	Brake Fern	Heavy Metals	Cu	Herbaceous
Pteris ensiformis Burm	Slender Brake Fern	Heavy Metals	As, Antimony	Herbaceous
Pteris fauriei		Heavy Metals	As, Antimony	
Pteris multifida	Spider Brake	Heavy Metals	As, Pb, Cd	
Pteris vittata	Hyperaccumulating Fern	Organics	Single super phosphate , di-ammonium phosphate (DAP), As, Fluoride	Herbaceous
Pteris vittata L.	Chinese Brake Fern	Organics	Diphenylarsinic acid	Herbaceous
Pterocarpus macrocarpus	Rosewood	Heavy Metals	Pb	
Puccinellia nuttalliana	Alkaligrass	Other	Landfill leachate	Herbaceous
Pusa Jai Kisan	Oilseed, Rapeseed	Heavy Metals	Ni	
Pyrus calleryana	Bradford Flowering Pear	Petroleum	Unspecified	Tree
Quercus acutissima Carruth	Sawtooth Oak	Heavy Metals	Zn, Pb ,Cu	
Quercus ilex subsp. Ballota	Holm Oak	Heavy Metals	Cd	Tree
Quercus macrocarpa	Bur Oak	Petroleum	BTEX	Tree

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Potential Accumulators	7–10	Europe, Asia, Africa	Ebbs et al., 2009
Accumulator			1) Feng R, Wang X, Wei C, Tu S. The accumulation and subcellular distribution of As and antimony in four fern plants. Int J Phytoremediation. 2015;17(1-6):348-354. doi:10.1080/15226514.2013.773281 2) De la Torre JB, Claveria RJ, Perez RE, Perez TR, Doronila AI. Cu uptake by Pteris melanocaulon Fée from a Cu-Gold mine in Surigao del Norte, Philippines. Int J Phytoremediation. 2016;18(5):435-441. doi:10.1080/15226514.2015.1109603
Accumulator			Feng R, Wang X, Wei C, Tu S. The accumulation and subcellular distribution of As and antimony in four fern plants. Int J Phytoremediation. 2015;17(1-6):348-354. doi:10.1080/15226514.2013.773284
Accumulator			Feng R, Wang X, Wei C, Tu S. The accumulation and subcellular distribution of As and antimony in four fern plants. Int J Phytoremediation. 2015;17(1-6):348-354. doi:10.1080/15226514.2013.773282
Accumulator			Rahman F, Sugawara K, Huang Y, Chien MF, Inoue C. As, Pb and Cd removal potential of Pteris multifida from contaminated water and soil. Int J Phytoremediation. 2018;20(12):1187-1193. doi:10.1080/15226514.2017.1375896
N/A			1) U.S EnvFemental Protection Agency (EPA). Phytoremediation field studies database for chlorinated solvents, pesticides, explosives, and metals. http://www.afcee.af.mil/shared/media/document/AFD-071130-018
Accumlator/Tolerant, Hyper-accumulator			1) http://scialert.net/qredirect.php?doi=jest.2011.118.138&linkid=pdf (Cr, Cu, Ni and Zn source) 2) Gui-Lan Duan, Y.-G. Zhu, Y.-P. Tong, C. Cai and R. Kneer (2005). â€œCharacterization of Arsenate Reductase in the Extract of Roots and Fronds of Chinese Brake Fern, an As Hyperaccumulatorâ€ (Pb, Hg, and As source) 4) (Phyto Textbook); (x2 articles) Ciurli, A., Lenzi, L., Alpi, A., and Pardossi, A. 2014. As uptake and translocation by plants in pot and field experiments. International Journal of Phytoremediation 16 (7-8), Special Issue: The 9th Interational Phytotechnology Society Conference -- Hasselt, Belgium 2012, pp. 804-823, DOI, 10.1080/15226514.2013.856850. ; Danh, L.T., Truong, P., Mammucari, R., and Foster, N. 2014. A crtical review of the As uptake mechanisms and phytoremediation potential of Pteris vittata. International Journal of Phytoremediation 16 (5), pp. 42
Accumulator			(Phyto Textbook) Meeinkuirt, W., Pokethitiyook, P., Kruatrachue, M., Tanhan, P., and Chairyarat, R. 2012. Phytostabilization of a Pb-contaminated mine tailing by various tree species in pot and field trial experiments. International Journal of Phytoremediation 14 (9), pp. 925-938.
Accumulator			Xu Q, Renault S, Yuan Q. Phytodesalination of landfill leachate using Puccinellia nuttalliana and Typha latifolia. Int J Phytoremediation. 2019;21(9):831-839. doi:10.1080/15226514.2019.1568383
Accumulator			Ansari MK, Ahmad A, Umar S, Zia MH, Iqbal M, Owens G. Genotypic variation in phytoremediation potential of Indian mustard exposed to Ni stress: a hydroponic study. Int J Phytoremediation. 2015;17(1-6):135-144. doi:10.1080/15226514.2013.862206
Tolerance	5–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator			Shi X, Chen YT, Wang SF, et al. Phytoremediation potential of transplanted bare-root seedlings of trees for Pb/Zn and Cu mine tailings. Int J Phytoremediation. 2016;18(11):1155-1163. doi:10.1080/15226514.2016.1189399
Excluder	7–11	Mediterranean	Dominguez et al., 2009
Degradation	3–8	North America	Cook and Hesterberg, 2012 Fagiolo and Ferro, 2004

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Quercus palustris	Pine Oak	Chlorinated Sol-vents	TCE, PCE, vinyl chloride	Tree
Quercus phellos	Willow Oak	Petroleum	Dioxin	Tree
Quercus robur	Oak	Heavy Metals	Cu, Zn, Cd, Pb	
Quercus virginiana	Live Oak	Chlorinated Sol-vents	TCE	Tree
Raphanus sativus	Radish	Heavy Metals	Heavy Metals and Hydro-carbons	
Raphanus sativus cv. Zhedachang	Radish	Heavy Metals	Cd	Herbaceous
Raphiolepis indica	Indian Hawthorne	Petroleum	Unspecified	Shrub
Rapistrum rugosum	Turnipweed	Heavy Metals	Pb	Herbaceous
Rhus chinensis Mill	Chinese Sumac	Heavy Metals	Zn, Pb ,Cu	
Rhus typhina	Staghorn Sumac	Heavy Metals	Ni, Polychlorinated Biphe-nyl (PCB)	
Ricinus communis	Castor Bean	Chlorinated Sol-vents	TCE	Herbaceous
Ricinus communis	Castor Oil Plant	Heavy Metals	Cd	Herbaceous
Rinorea bengalensis	Bengal Rinorea	Heavy Metals	Ni	
Robinia pseudoacacia	Black Locust	Petroleum	PAH MOH	Tree
Robinia pseudoacacia	Black locust		Histidine, Ni	
Rorippa globosa	Globe Yellowcress	Heavy Metals	Cd	Herbaceous
Rosa multiflora	Multiflora Rose	Heavy Metals	Cr, Ni, Cu, Zn, Cd	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation	4–8	Eastern USA	Ferro et al., 2000
Degradation	6–9	North America	Ferro et al., 2013
Accumulator			(Phyto Textbook) Evangelou, M.W., Robinson, B.H., Gunthardt-Goerg, M.S., and Schlin, R. 2013. Metal uptake and allocation in trees grown on contaminated land: implications for biomass production. International Journal of Phytoremediation 15 (1), pp. 77-90.
Degradation	7–10	Southeastern USA	Hayhurst et al., 1998 ITRC PHYTO 3
Accumulator			1) U.S EnvFemental Protection Agency (EPA). Phytoremediation field studies database for chlorinated solvents, pesticides, explosives, and metals. http://www.afcee.af.mil/shared/media/document/AFD-071130-018 3) (Phyto Textbook) Macci, C., Doni, S., Peruzzi, E., Bardella, S., Filippis, G., Ceccanti, B., and Masciandaro, G. 2012. A real-scale soil phytoremediation. Biodegredation 24 (4) pp. 521-541
Accumulator	Grown as annual	Europe	Ding et al., 2013
Tolerance	8–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator			Saghi A, Rashed Mohassel MH, Parsa M, Hammami H. Phytoremediation of Pb-contaminated soil by Sinapis arvensis and Rapistrum rugosum. Int J Phytoremediation. 2016;18(4):387-392. doi:10.1080/15226514.2015.1109607
Accumulator			Shi X, Chen YT, Wang SF, et al. Phytoremediation potential of transplanted bare-root seedlings of trees for Pb/Zn and Cu mine tailings. Int J Phytoremediation. 2016;18(11):1155-1163. doi:10.1080/15226514.2016.1189399
Hyperaccumulator			1) University of Minnesota Sustainable Urban Landscape Information Series. http://www.sustland.umn.edu/design/water4.html
Degradation	9–11	Middle East	Hayhurst et al., 1998 ITRC PHYTO 3
Accumulator	10–11	Mediterranean East Africa	Bauddh and Singh, 2012
Hyperaccumulator			Hamdan AM, Bijaksana S, Tjoa A, Dahrin D, Kirana KH. Magnetic characterizations of Ni hyperaccumulating plants (Planchonella oxyhedra and Rinorea bengalensis) from Halmahera, Indonesia. Int J Phytoremediation. 2019;21(4):364-371. doi:10.1080/15226514.2018.1524839
Degradation	4–9	North America	Gawronski et al., 2011 Tischer and Hubner, 2002
Accumulator/Tolerant, Hyperaccumulator			1) Leigh, M.B., J. Fletcher, D.P. Nagle, P. Prouzova, M. Mackova and T. Macek (2003) Rhizoremediation of PCBS: Mechanistic and Field Investigations 2) Kang W, Bao J, Zheng J, Xu F, Wang L. Phytoremediation of heavy metal contaminated soil potential by woody plants on Tonglushan ancient Cu spoil heap in China. Int J Phytoremediation. 2018;20(1):1-7. doi:10.1080/15226514.2014.950412 3) Ozen SA, Yaman M. Examination of correlation between histidine and Ni absorption by Morus L., Robinia pseudoacacia L. and Populus nigra L. using HPLC-MS and ICP-MS. Int J Phytoremediation. 2016;18(8):794-800. doi:10.1080/15226514.2015.1131243
Accumulator	6	Europe	Wei and Zhou, 2006
Accumulator			Antonkiewicz J, Ko?odziej B, Bieli?ska EJ. Phytoextraction of heavy metals from municipal sewage sludge by Rosa multiflora and Sida hermaphrodita. Int J Phytoremediation. 2017;19(4):309-318. doi:10.1080/15226514.2016.1225283

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Rosa ssp.	Paul's Scarlet Rose		Polychlorinated Biphenyl (PCB)	
Ruellia geminiflora	Ipecacuanha	Heavy Metals	Ni	Herbaceous
Rumex acetosa	Rumex	Heavy Metals	Zn	Herbaceous
Rumex acetosa	Common Sorrel	Radionuclides	137Cs	Herbaceous
Rumex crispus	Curly Dock	POP	PCB	Herbaceous
Rumex crispus	Curly Dock	Heavy Metals	Cd, Zn	Herbaceous
Rumex pictus	Dock	Radionuclides	Th, U	Herbaceous
Rumohra adiantiformis	Leather Leaf Fern	Petroleum	Unspecified	Herbaceous
Sabel minor	Palmetto Bush	Petroleum	Unspecified	Shrub
Saccharum spp.	Sugarcane	Pesticides	2,4-D	Herbaceous
Sagittaria latifolia	Arrowhead	Petroleum	TPH	Herbaceous
Sagittaria spp.	Arrowhead	Explosives	RDX	Wetland
Salicornia depressa	Virginia Glasswort	Heavy Metals	Cd, Pb	
Salicornia persica	Akhani	Petroleum	Petroleum hydrocarbon, Salt	
Salix	Willow	Heavy Metals	Cd, Cu, Ni, Zn	
Salix alaxensis	Felt-Leaf Willow	Petroleum	TPH	Tree/Shrub
Salix alba	White Willow	Petroleum	BTEX	Tree
Salix alba	White Willow	Petroleum	petroleum hydrocarbon Total petroleum hydro-carbons	Tree
Salix alba "Niobe"	Niobe Weeping Willow	Heavy Metals	Cr, Hydrocarbons, Hg, Organic Solvents, Ag	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Hyperaccumulator	Not available	South America	Jaffré and Schmid, 1974 Brooks et al., 1992
Hyperaccumulator	3–7	Europe	Reeves, 2006
Extraction	3–9	Europe, Asia	ITRC PHYTO 3 Olsen, 1994
Extraction	5+	Eurasia	Ficko et al., 2011
Accumulator	1–11	Europe, Asia	Zhuang et al., 2007
Extraction	Not available	Middle East	Hegazy and Emam, 2011
Tolerance	9–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Tolerance	7–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Degradation or hydraulic control	9+	Central and South America	Anderson et al., 1993 ITRC PHYTO 3
Degradation	5–10	North America, South America	Cook and Hesterberg, 2012 Euliss et al., 2008
Degradation	5–10	North and South America	Kiker and Larson, 2001
N/A			1) Gallagher, J.L and H.V. Kibby, 1980. Marsh plants as vectors in trace metal transport in Oregon tidal marshes. American Journal of Botany, 67: 1069-1074
Accumulator			(Phyto Textbook) Leewis, M.,-C., Reynolds, C. M., and Leigh, M. B. 2013. Long-term effects of nutrient addition and phytoremediation on diesel and crude oil contaminated soils in subarctic Alaska. Cold Regions Science and Technology, DOI, 10.1016/j.coldregions.2013.08.011.
Accumulator			1) (Phyto Textbook) Lee, K. Y., and Doty, S. L. 2012. Phytoremediation of chlorpyrifos by Populus and Salix. International Journal of Phytoremediation 14 (1), pp. 48-61. 2) Greger M, Landberg T. Novel Field Data on Phytoextraction: Pre-Cultivation With Salix Reduces Cd in Wheat Grains. Int J Phytoremediation. 2015;17(10):917-924. doi:10.1080/15226514.2014.1003785
Degradation	2–8	Alaska, Canada	Cook and Hesterberg, 2012 Soderlund, 2006
Degradation	2–8	Europe, Asia	Cook and Hesterberg, 2012 Fagiolo and Ferro, 2004 Ferro et al., 2013
Degradation	2–9	Europe, Asia	2) Ferro, A., Chard, B., Gefell, M., Thompson, B., and R. Kjelgren. 2000. â€œPhytoremediation of Organic Solvents in Groundwater: Pilot Study at a Superfund Siteâ€ . In: G. Wickramanayake, A. Gavaskar, B. Alleman, and V. Magar (eds.) Bioremediation and Phytoremediation of Chlorinated and Recalcitrant Compounds, p461-466. Battelle Press, Columbus, Ohio.; Ferro, A., Kennedy, J., Kjelgren, R., Rieder, J., and S. Perrin. 1999. â€œToxicity Assessment of Volatile Organic Compounds in Poplar Treesâ€ . International Journal of Phytoremediation. 1(1): 9-17. 3) (Phyto Textbook) Ferro, A.M., Adham, T., Berra, B., and Tsao, D. 2013. Performance of deep-rooted phreatophytic trees at a site containing total petroleum hydrocarbons. International Journal of Phytoremediation 15 (3), pp. 232-244.
N/A			1) http://tinyurl.com/6wv87g8ved=0CEAQ6AEwAA#v=onepage&q&f=false

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Salix alba "Tristis"	Golden Weeping Willow	Heavy Metals	As, Benzene, Chloroform, Pb, Hg, Ni, Perchloroethylene (PCE), P, Ag, Toluene, Trichloroethylene (TCE) and by-products, Tritium, Zn	
Salix alba L. 'Britzensis'	Coralbark Willow	Pesticides	Trifluralin Metalaxyl	Shrub
Salix babylonica L.	Weeping Willow	Petroleum	MTBE TBA (Tert-butyl Alcohol)	Tree
Salix caprea	Goat Willow	POP	PCB	Shrub
Salix caprea	Goat Willow	Radionuclides	Sr, Cs	Shrub
Salix dasyclados	Shrub Willow	Petroleum	Total petroleum hydrocarbons	
Salix exigua	Narrowleaf Willow		Trichloroethylene (TCE) and by-products	
Salix interior	Sandbar Willow		Polychlorinated Biphenyl (PCB), Polycyclic Aromatic Hydrocarbon (PAH)	
Salix matsudana	Chinese Willow	Heavy Metals	Cu, Cd	
Salix nigra	Black Willow	Petroleum	PAH, BTEX, TPH	Tree/Shrub
Salix nigra	Black Willow	Pesticides	Bentazone	Tree/Shrub
Salix pentandra	Laurel-Leaved Willow	Heavy Metals	As, Chloroform, Pb, Perchloroethylene (PCE), Trichloroethylene (TCE) and by-products, Tritium, Zn	
Salix pentaphyllum "Prairie Cascade"	Prarie Cascade Willow	Heavy Metals	As, Chloroform, Pb, Perchloroethylene (PCE), Trichloroethylene (TCE) and by-products, Tritium, Zn	
Salix rubens	Hybrid Crack Willow	Heavy Metals	Cd, Zn, Cu	
Salix spp.	Willow	Chlorinated Solvents	PCE, TCE	Shrub/Tree
Salix spp.	Willow	Pesticides	Chlorpyrifos	Shrub/Tree
Salix spp.	Willow	Radionuclides	137Cs, 90Sr	Shrub/Tree

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
N/A			1) Negri, M.C., et al 2003 Root Development and Rooting at Depths, in S.C. McCutcheon and J.L. Schnoor, eds., Phytoremediation: Transformation and Control of Contaminants: Hoboken, NJ, John Wiley & Sons, Inc. p233-262, 912-913 Quinn, J.J., et al 200 Predicting the Effect of Deep-Rooted Hybrid Poplars on the Groundwater Flow System at a Phytoremediation Site: International Journal of Phytoremediation, vol. 3, no. 1, p. 41-60
Degradation or hydraulic control	2+	Europe, Asia	Warsaw et al., 2012
Degradation	6–9	China	Yu and Gu, 2006
Extraction	4–8	Europe, Asia	Leigh et al., 2006
Extraction	4–8	Europe, Asia	Dutton and Humphreys, 2005
Accumulator			
N/A			1) http://en.wikipedia.org/wiki/List_of_hyperaccumulators 2) Jordahl, J., R. Tossell, M. Barackman and G. Vogt (2003) Phytoremediation for Hydraulic Control and Remediation: Beale 3) Air Force Base and Koppel Stockton Terminal. Abstracts from US EPA International Applied Phytotechnologies Workshop March 3-5, 2003 Chicago, IL
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Accumulator			Wang WW, Ke Cheng L, Hao JW, Guan X, Tian XJ. Phytoextraction of initial cutting of Salix matsudana for Cd and Cu. Int J Phytoremediation. 2019;21(2):84-91. doi:10.1080/15226514.2016.1183574
Degradation	2–8	Eastern USA	Spriggs et al., 2005 Guthrie Nichols et al., 2014
Degradation or hydraulic control	2–8	Eastern USA	Conger, 2003 Conger and Portier, 2006
N/A			1) Negri, M.C., et al 2003 Root Development and Rooting at Depths, in S.C. McCutcheon and J.L. Schnoor, eds., Phytoremediation: Transformation and Control of Contaminants: Hoboken, NJ, John Wiley & Sons, Inc. p233-262, 912-913 Quinn, J.J., et al 200 Predicting the Effect of Deep-Rooted Hybrid Poplars on the Groundwater Flow System at a Phytoremediation Site: International Journal of Phytoremediation, vol. 3, no. 1, p. 41-60
N/A			1) Negri, M.C., et al 2003 Root Development and Rooting at Depths, in S.C. McCutcheon and J.L. Schnoor, eds., Phytoremediation: Transformation and Control of Contaminants: Hoboken, NJ, John Wiley & Sons, Inc. p233-262, 912-913 Quinn, J.J., et al 200 Predicting the Effect of Deep-Rooted Hybrid Poplars on the Groundwater Flow System at a Phytoremediation Site: International Journal of Phytoremediation, vol. 3, no. 1, p. 41-60
Accumulator			Kacálková L, Tlustoš P, Száková J. Phytoextraction of risk elements by willow and poplar trees. Int J Phytoremediation. 2015;17(1-6):414-421. doi:10.1080/15226514.2014.910171
Degradation	4–10	Southwestern USA	Stanhope et al., 2008 Landmeyer, 2012
Degradation or hydraulic control	4–11	Southwestern USA	Lee et al., 2012
Extraction	4–12	Southwestern USA	Vandenhove et al., 2004

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Salix spp. Salix interior Salix exigua	Willow	Petroleum	DRO TPH BTEX PAH	Tree/Shrub
Salix spp. 'Belders' (S. alba L. var. alba), 'Belgisch Rood' (S. × rubens var. basfordiana) (Zwaenepoel et al., 2005), 'Christina' (S. viminalis), 'Inger' (S. triandra × S. viminalis), 'Jorr' (S. viminalis), 'Loden' (S. dasyclados), 'Tora' (S. schwerinii × S. viminalis) and 'Zwarte Driebast' (S. triandra). Salix viminalis L.	Willow	Heavy Metals	Cd, Zn	Shrub
Salix ssp.	Hybrid Willow	Heavy Metals	Cd, Cr, Cu, Ni, Polycyclic Aromatic Hydrocarbon (PAH), Ag, Zn	
Salix viminalis	Basket Willow	Petroleum	PAH	Shrub
Salix viminalis	Basket Willow	Heavy Metals	Cd, Mg, Fe, Cu, Pb, Ni, Zn	Shrub
Salix x auero-pendula CL-J(11)	Weeping Willow		PHE (phenanthrene, PHEr Cd)	
Salix x smithiana Wiild	Smith Willow	Heavy Metals	Cd, Zn, Cu	Shrub
Salsola kali	Russian Thistle	Radionuclides	Cs, Sr	Herbaceous
Salvia sclarea	Clary	Heavy Metals	Cr, Ni, Fe, Pb	Herbaceous
Salvinia minima	Water spangles	Heavy Metals	Cd, Ni, Pb, Zn	Herbaceous
Sambucus nigra L. 'Aurea'	Elderberry	Pesticides	Trifluralin Metalaxyl	Shrub

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation	Varies	Worldwide	Applied Natural Sciences, Inc., 1997 Carman et al., 1997, 1998 Coltrain, 2004 Cook et al., 2010 Cook and Hesterberg, 2012 Euliss et al., 2008 ITRC PHYTO 3 Kulakow, 2006b Kulakow, 2006c
Accumulator	varies	varies	Algreen et al., 2013 Evangelou et al., 2012 Ruttens et al., 2011 Thewys et al., 2010 Van Slycken et al., 2012 Van Slycken et al., 2013 Witters et al., 2012
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf 2) Interstate Technologoy and Regulation Cooperation Work Group. Phytoremediation Decision Tree, ITRC. http://www.itrcweb.org/documents/phyto-1.pdf
Degradation	4–10	Europe, Asia	Cook and Hesterberg, 2012 Hultgren et al., 2010 Hultgren et al., 2009 Roy et al., 2005
Accumulator, Hyperaccumulator			1) Enhancing Phytoextraction: The Effect of Chemical Soil Manipulation on Mobility, Plant Accumulation, and Leaching of Heavy Metals, by Ulrich Schmidt. 2) Yu X.Z., Zhou P.H. and Yang Y.M., The potential for phytoremediation of Fe cyanide complex by Willows. 3) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. pg 19 5) Borišev M, Pajevi? S, Nikoli? N, et al. Mg and Fe deficiencies alter Cd accumulation in Salix viminalis L. Int J Phytoremediation. 2016;18(2):164-170. doi:10.1080/15226514.2015.1073670 6) (Phyto Textbook) Efe, S.I., and Okpali, A.E. 2012. Management of petroleum impacted soil with phytoremediation and soil amendments in Expan Delta State, Nigeria. Journal of EnvFemental Protection 3, pp. 386-393. 7) (Phyto Textbook) Algreen, M., Trapp, S., and Rein, A. 2013. Phytoscreening an
Accumulator			Sun, Y. Y., et al. "Phytoremediation of Soils Contaminated with Phenanthrene and Cd by Growing Willow (Salix×Aureo-PendulaCL 'j1011')." International Journal of Phytoremediation, vol. 18, no. 2, 2015, pp. 150–156., doi:10.1080/15226514.2015.1073668.
Accumulator			Kacálková L, Tlustoš P, Száková J. Phytoextraction of risk elements by willow and poplar trees. Int J Phytoremediation. 2015;17(1-6):414-421. doi:10.1080/15226514.2014.910171
Extraction	8–10	Europe, Asia	Negri and Hinchman, 2000 from Arthur, 1982 and Blanchfield and Hoffman, 1984
Accumulator			Chand S, Yaseen M, Rajkumari, Patra DD. Application of Heavy Metal Rich Tannery Sludge on Sustainable Growth, Yield and Metal Accumulation by Clarysage (Salvia sclarea L.). Int J Phytoremediation. 2015;17(12):1171-1176. doi:10.1080/15226514.2015.1045128
Accumulator			Iha DS, Bianchini I Jr. Phytoremediation of Cd, Ni, Pb and Zn by Salvinia minima. Int J Phytoremediation. 2015;17(10):929-935. doi:10.1080/15226514.2014.1003793
Degradation or hydraulic control	4+	Europe, Asia, Africa	Warsaw et al., 2012

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Sansevieria	Snakeplant		Trimethylamine	
Sansevieria trifasciata	Snake Plant		Trimethylamine	
Schizachyrium scoparium	Little Bluestem	Petroleum	PAH	Herbaceous
Schizachyrium scoparium	Little Bluestem	Heavy Metals	Cu	Herbaceous
Schoenoplectus lacustris	Bulrush	Petroleum	Phenol	Wetland
Scirpus acutus	Hardstem Bulrush	Petroleum	Benzene	Wetland
Scirpus atrovirens	Green Bulrush	Petroleum	PAH	Wetland
Scirpus cyperinus	Woolgrass	Explosives	RDX TNT	Herbaceous
Scirpus maritimus	Alkali Bulrush	Petroleum	TPH	Wetland
Scirpus spp.	Bulrush	Petroleum	Phenol Biological oxygen demand Chemical oxygen demand Oil and gasoline Phenol Total suspended solids	Wetland
Sebertia acuminata	Latex Rubber Tree	Heavy Metals	Ni	Tree/Shrub
Secale cereale	Winter Rye	Petroleum	Pyrene TPH PAH	Herbaceous
Sedum	Sedum	Heavy Metals	Cd, Zn	Herbaceous
Sedum alfredii	Sedum	Heavy Metals	Cd, Zn	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Tolerant			Boraphech P, Suksabye P, Kulinfra N, Kongsang W, Thiravetyan P. Cleanup of trimethylamine (fishy odor) from contaminated air by various species of Sansevieria spp. and their leaf materials. Int J Phytoremediation. 2016;18(10):1002-1013. doi:10.1080/15226514.2016.1183569
Accumulator			1) B.C Wolverton Ph.D -Principal investigator. NASA. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930073077_1993073077.pdf 2) Plants "Clean" Air Inside Our Homes (kilde NASA) 3) Wolverton, B.C. (1996) How to Grow Fresh Air. New York: Penguin Books. 4) B. C. Wolverton and J.D. Wolverton. "Plants and Soil Microorganisms: Removal of Formaldehyde, Xylene, Ammonia From the Indoor EnvFement". Retrieved 2011-08-27.
Degradation	2–7	Eastern USA	Aprill and Sims, 1990 Cook and Hesterberg, 2012 Pradhan et al., 1998 Rugh, 2006
N/A	2–8	Eastern USA	1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Degradation	5–10	North America	ITRC PHYTO 3 Kadlec and Knight, 1996
N/A	4–7	North America	1) http://www.wallawallanursery.com/detail.cfm?gotopage=11&nid=2640&SearchGroup=grasses&SearchGen=&SearchVar=&SearchSPE=
Degradation	4–8	North America	Thomas et al., 2012
Degradation	4–8	North America	Best et al., 1997 Best et al., 1999.
Degradation		North America	Couto et al., 2012
Degradation	Varies	Worldwide	ITRC PHYTO 3 Kadlec and Knight, 1996
Hyperaccumulator	Not available	New Caledonia	Cunningham and Berti, 1993 ITRC PHYTO 3 Van der Ent et al., 2013
Degradation	3+	Asia	Cook and Hesterberg, 2012 ITRC PHYTO 3 Kulakow, 2006a Kulakow, 2006b Muratova et al., 2008 Reynolds et al., 1998
Tolerant, Hyperaccumulator			1) Analysis of Phytoscapes Species for BP Retail Sites. Kim Tsao. David Tsao, Ph.D. BP Group EnvFemental Management Company. 28 March 2003 2) (Phyto Textbook) Xing, Y., Peng, H., Gao, L., Luo, A., and Yang, X. 2013. A Compound Containing Substituted Indole Ligand from a Hyperaccumulator Sedum Alfredii Hance Under Zn Exposure. International Journal of Phytoremediation 15 (10), pp. 952-964. - Pan F, Meng Q, Luo S, et al. Enhanced Cd extraction of oilseed rape (Brassica napus) by plant growth-promoting bacteria isolated from Cd hyperaccumulator Sedum alfredii Hance. Int J Phytoremediation. 2017;19(3):281-289. doi:10.1080/15226514.2016.1225280 3) (Phyto Textbook) Lu, L., Tian, S., Yang, X., Peng, H., and Li, T. 2013. Improved Cd uptake and accumulation in the hyperaccumulator Sedum alfredii: the impact of citric acid and tartaric acid. Journal of Zhejiang University Science B 14 (2), pp. 106-114. 4) (Phyto Textbook) Wang, K., Huang, H., Zhu, Z., Li, T., He, Z., Yang, X., and Alva,
Accumulator	Not available	Asia	Li et al., 2011 Lu et al., 2013 Wang et al., 2012 Xiaomei et al., 2005 Xing et al., 2013 Yang et al., 2013 Zhuang et al., 2007

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Sedum jinianum	Sedum	Heavy Metals	Cd, Zn	Herbaceous
Sedum mexicana	Sedum	Petroleum	Unspecified	Herbaceous
Sedum plumbiZnicola	Sedum	Heavy Metals	Cd, Zn	Herbaceous
Senecio glaucus	Jaffa Groundsel	Radionuclides	Th, U	Herbaceous
Senecio pauperculus	Balsam Groundsel	Heavy Metals	Ni	Herbaceous
Senecio salignus	Barkleyanthus	Heavy Metals	Zn	
Senna obtusifolia	Coffee Weed	Petroleum	PAH	Herbaceous
Serenoa repens	Saw Palmetto	Chlorinated Sol-vents	TCE	Tree
Sesamum indicum	Sesame	POP	Lindane (-HCH)	Herbaceous
Sesbania asper	Sesbania	Heavy Metals	Unspecified	
Sesbania drummondi	Rattlebush, Poison Bean	Heavy Metals	Cd	Shrub
Sesbania punicea	Red sesbania	Heavy Metals	Unspecified	
Sesuvium portulacastrum L.	Shoreline Purslane	Heavy Metals	Cr, Cd, Zn, Cu, NaCl	
Sida hermaphrodita	Virginia Mallow, Virginia fanpetals	Heavy Metals	Zn, Pb, Cr, Ni, Cu, Zn, Cd	
Silene paradoxa	Silene	Heavy Metals	As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn	Herbaceous
Silene vulgaris	Bladder Campion	Heavy Metals	Cd, Zn	
Silybum marianum	Milk Thistle	Heavy Metals	Cd, Cr, Cu, Ni, Pb, Zn	Herbaceous
Sinapis alba	White mustard	Heavy Metals	Cd	
Sinapis arvensis	Charlock Mustard	Heavy Metals	Unspecified	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator	Not available	China	Xu et al., 2009
Tolerance	7–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator	Not available		Liu et al., 2011
Extraction	Not available	Europe, Asia, Africa	Hegazy and Emam, 2011
Hyperaccumulator	1–10	North America	Baker and Reeves, 2000 Roberts, 1992
Accumulator			(Phyto Textbook) Cortes-Jimenez, E., Mugica-Alvarez, V., Gonzalez-Chavez, M., Carrillo-Gonzalez, R., Gordillo, M., and Mier, M. 2013. Natural revegetation of alkaline tailing heaps at Taxco, Guerrero, Mexico. International Journal of Phytoremediatio15 (2), pp. 127-141.
Degradation	7+	North America, South America	Cook and Hesterberg, 2012 Euliss, 2004
Degradation	8–11	Southeastern USA	Hayhurst et al., 1998 ITRC PHYTO 3
Extraction	9–11	Africa	Abhilash and Singh, 2010
Hyperaccumulator			Mishra T, Singh NB, Singh N. Restoration of red mud deposits by naturally growing vegetation. Int J Phytoremediation. 2017;19(5):439-445. doi:10.1080/15226514.2016.1244162
Accumulator	8–11	Southeastern USA	Israr et al., 2006
Hyperaccumulator			Mishra T, Singh NB, Singh N. Restoration of red mud deposits by naturally growing vegetation. Int J Phytoremediation. 2017;19(5):439-445. doi:10.1080/15226514.2016.1244162
Accumulator			Ayyappan D, Sathiyaraj G, Ravindran KC. Phytoextraction of heavy metals by Sesuvium portulacastrum l. a salt marsh halophyte from tannery effluent. Int J Phytoremediation. 2016;18(5):453-459. doi:10.1080/15226514.2015.1109606
Accumulator			1) (Phyto Textbook) Kocon, A., and Matyka, M. 2012. Phytoextractive potential of Miscanthus giganteus and Sida hermaphrodita growing under moderate pollution of soil with Zn and Pb. Journal of Food, Agriculture and EnvFement 10 (2), pp. 1253-1256. 2) Antonkiewicz J, Ko?odziej B, Bieli?ska EJ. Phytoextraction of heavy metals from municipal sewage sludge by Rosa multiflora and Sida hermaphrodita. Int J Phytoremediation. 2017;19(4):309-318. doi:10.1080/15226514.2016.1225283
Excluder	6+	Southern Europe	Pignattelli et al., 2012
N/A			1) Oyler, J. Blue Mountain Superfund Remediation Project, Palmerton, PA. Powerpoint presentation. June 10, 2004. ITRC Phytotechnologies conference
Excluder	5–9	Southern Europe	Perrino et al., 2012 Perrino et al., 2013
Accumulator			Bulak P, Lata L, Plak A, et al. Electromagnetic field pretreatment of Sinapis alba seeds improved Cd phytoextraction. Int J Phytoremediation. 2018;20(4):338-342. doi:10.1080/15226514.2017.1381943
Accumulator			1) Saghi A, Rashed Mohassel MH, Parsa M, Hammami H. Phytoremediation of Pb-contaminated soil by Sinapis arvensis and Rapistrum rugosum. Int J Phytoremediation. 2016;18(4):387-392. doi:10.1080/15226514.2015.1109607 2) (Phyto Textbook) Perrino, E. V., Brunetti, G., and Farrag, K. 2013. Plant communities in multi-metal contaminated soils: a case study in the National Park of Alta Murgia (Apulia region-Southern Italy). International Journal of Phytoremediation 16, pp. 871-888.

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Sinapis arvensis L.	Wild Mustard	Heavy Metals	Zn, Cd, Pb, Cu	Herbaceous
Solanum elaegnofolium	Purple Nightshade	Heavy Metals	Cd	Herbaceous
Solanum nigrum	Black Nightshade	Heavy Metals	As	Herbaceous
Solanum nigrum	Black Nightshade	Heavy Metals	Cd, Ni, Zn	Herbaceous
Solanum surattense	Solanum surattense	Heavy Metals	Fe, Mn, Cu, Pb, Cr, Ni, Cd	
Solanum torvum L.	Turkey Berry	POP	Lindane, HCH	Herbaceous
Solanum tuberosum	Potato	Radionuclides	137Cs, 106Ru	Herbaceous
Solanum tuberosum cv. Luyin No.1	Potato	Heavy Metals	Cd	Herbaceous
Solidago canadensis	Canadian Goldenrod	POP	PCB	Herbaceous
Solidago hispida	Hairy Goldenrod	Heavy Metals	Ni	Herbaceous
Solidago hispida	Hairy Golden Rod		Trichloroethylene (TCE) and by-products	
Solidago spp.	Goldenrod	Petroleum	TPH PAH	Herbaceous
Solidago spp.	Goldenrod	Chlorinated Sol-vents	PCE, TCE	Herbaceous
Sonchus transcaspicus	Sowthistle	Heavy Metals	Ni, Cu, Cd, Co, Mn, Cr, Zn	Herbaceous
Sorghastrum nutans	Indiangrass	Petroleum	TPH PAH	Herbaceous
Sorghastrum nutans var. Holt	Yellow Indiangrass	Pesticides	Altrazine Pendimethalin	Herbaceous
Sorghum bicolor	Broom-corn	Heavy Metals	Cr	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Excluder	6+	Mediterranean	Perrino et al., 2012
Accumulator	6+	Western USA, South America	Gardea-Torresdey et al., 1998 ITRC PHYTO 3
Potential Accumulators		Europe, Asia	Gisbert et al., 2008
Accumulator	4–7	Eurasia	Ji et al., 2011 Wei et al., 2004 Wei et al., 2012
Accumulator			Pandey SK, Bhattacharya T, Chakraborty S. Metal phytoremediation potential of naturally growing plants on fly ash dumpsite of Patratu thermal power station, Jharkhand, India. Int J Phytoremediation. 2016;18(1):87-93. doi:10.1080/15226514.2015.1064353
Extraction	9+	North and Central America	Abhilash et al., 2008
Extraction	Grown as annual	South America	Bell et al., 1988 ITRC PHYTO 3
Accumulator	3–12		Ding et al., 2013
Extraction	3+	Northeastern North America	Ficko et al., 2010 Ficko et al., 2011
Hyperaccumulator	3–8	Eastern North America	Baker and Reeves, 2000
Hyperaccumulator, Accumulator			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plan_species_phyto.pdf 2) Grauer & Horst 1990; McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant_species_phyto.pdf pg 891
Degradation	Varies	North and South America, Europe, Asia	Cook and Hesterberg, 2012 Kulakow, 2006b
Degradation	4–9	North America	Anderson et al., 1991, 1992 ITRC PHYTO 3
Accumulator	4–9	Europe Asia	Lu et al., 2013
Degradation	2–9	North America	Aprill and Sims, 1990 Cook and Hesterberg, 2012
Degradation or hydraulic control	2–9	North America	Henderson et al., 2006
Accumulator/Tolerant			1) (Phyto Textbook) Soudek, P., Petrova, S., Vankova, R., Song, J., and Vanek, T. 2014. Accumulation of heavy metals using Sorghum sp.. Chemosphere 104, pp. 15-24. 2) Ariana Carramaschi Francato Zancheta, Cleide Aparecida De Abreu, Fernando César BachiegaZambrosi, Norma de Magalhães Erismann & Ana Maria Magalhães Andrade Lagôa (2015) Cd Accumulationby Jack-Bean and Sorghum in Hydroponic Culture, International Journal of Phytoremediation, 17:3, 298-303, DOI:10.1080/15226514.2014.883492 (6) (PDF) Cd Accumulation by Jack-Bean and Sorghum in Hydroponic Culture. Available from: https://www.researchgate.net/publication/268336638_Cd_Accumulation_by_Jack-Bean_and_Sorghum_in_Hydroponic_Culture [accessed Jun 25 2020]. 3) Padmapriya S, Murugan N, Ragavendran C, Thangabalu R, Natarajan D. Phytoremediation potential of some agricultural plants on heavy metal contaminated mine waste soils, salem district, tamilnadu. Int J Phytoremediation. 2016;18(3):288-294. doi:10.1080/15226514.

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Sorghum bicolor Sorghum bicolor subsp. Drum-mondii	Sorghum	Petroleum	TPH Anthracene Pyrene	Herbaceous
Sorghum halepense (L.)	Johnson Grass, Aleppo Grass	Heavy Metals	Al, As, Cs, Cu, Hydrocar-bons, Mn, Ni, U, Zn	Herbaceous
Sorghum sudanense	Sorghum	Radionuclides	Cs	Herbaceous
Sorghum sundase	Sorghum	Explosives	RDX	Herbaceous
Sorghum vulgare	Sudan Grass	Petroleum	PAH	Herbaceous
Sparganium eurycarpum	Common Bur-reed	Heavy Metals	Pb	
Spartina foliosa	Cordgrass	Petroleum	Atrazine, Petroleum, Trichloroethylene (TCE) and by-products	Herbaceous
Spartina pectinata	Prairie Cordgrass	Petroleum	PAH	Herbaceous
Spartina pectinata	Prairie Cordgrass	POP	PCB	Herbaceous
Spinacia oleracea	Spinach		20- Hydroxyecdysone	
Spinacia oleracea L. cv. Monnopa	Spinach	Heavy Metals	Cd	Herbaceous
Spiraea spp.	Neon Flash	Petroleum	Unspecified	Shrub
Spirea sp.	Neon Flash	Petroleum	Petroleum	
Spirodela polyrhiza	Giant Duckweed	Heavy Metals	Al, As, Cd, Nitrate	Herbaceous
Stanleya bipinnata	Bipinnate Prince's Plume	Heavy Metals	Se	Herbaceous
Stanleya pinnata	Prince's Plume	Heavy Metals	Se	Herbaceous
Stellaria calycantha	Northern Starwort	Heavy Metals	Cd	

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation	8+	Africa	Cook and Hesterberg, 2012 Flathman and Lanza, 1998 ITRC PHYTO 3 Liu et al., 2010 Muratova et al., 2008 Nedunuri et al., 2000 Reilley et al., 1996 Reilley et al., 1993 Schwab and Banks, 1994
Accumulator			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. 2) Phytoremediation of RadioÂ¬nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm (Al source)
Extraction	8+	Africa	Negri and Hinchman, 2000
Degradation	8+	Africa	Chen et al., 2011
Degradation	8+	Africa	Reilley et al., 1996
Accumulator			1) University of Minnesota Sustainable Urban Landscape Information Series. http://www.sustland.umn.edu/design/water4.html
Accumulator of TCE, Petroleum, and Atrazine			1) http://www.jandcwaterworks.com/most-desirable-plants.htm
Degradation	5+	North America	Cook and Hesterberg, 2012 Rugh, 2006
Extraction	4–9	North America	Smith et al., 2007
Accumulator/Tolerant			1) Bareen FE, Saeed S, Afrasiab H. Differential mobilization and metal uptake versus leaching in multimetal soil columns using EDTA and three metal bioaccumulators. Int J Phytoremediation. 2017;19(12):1109-1117. doi:10.1080/15226514.2017.1328391 2) Muchate NS, Rajurkar NS, Suprasanna P, Nikam TD. Evaluation of Spinacia oleracea (L.) for phytodesalination and augmented production of bioactive metabolite, 20-hydroxyecdysone. Int J Phytoremediation. 2018;20(10):981-994. doi:10.1080/15226514.2018.1452184
Accumulator	Grown as annual	Asia	Stritsis et al., 2014
Tolerance	4–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Tolerant			
Hyperaccumulator of Nitrate			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf. pg 898 (Al, As, and Cd source) 3) McCutcheon & Schnoor 2003, Phytoremediation. New Jersey, John Wiley & Sons pg 898, 891 4) Movafeghi A, Khataee AR, Moradi Z, Vafaei F. Biodegradation of direct blue 129 diazo dye by Spirodela polyrrhiza: An artificial neural networks modeling. Int J Phytoremediation. 2016;18(4):337-347. doi:10.1080/15226514.2015.1109588
Hyperaccumulator	Not available	Western North America	Baker and Reeves, 2000 Byers et al., 1938 Moxon et al., 1950 Rosenfeld and Beath, 1964
Hyperaccumulator	3–7	Western North America	Baker and Reeves, 2000 Byers et al., 1938 Rosenfeld and Beath, 1964 Van der Ent et al., 2013 White et al., 2007
Accumulator			1) Institute for EnvFemental Research and education (IERE). (2003 January). Vashon Heavy Metal Phytoremediation Study Sampling and Analysis Strategy (DRAFT). http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Stellaria media	Chickweed	Heavy Metals	Cs	Herbaceous
Stenotaphrum secundatum	St. Augustine Grass	Petroleum	TPH PAH	Herbaceous
Stephanandra incisa	Laceshrub	Other	Particulate matter	
Stipa austroitalica Martinovský subsp. Austroitalica	Stipa	Heavy Metals	Zn, Cd, Pb, Cu	Herbaceous
Strelitzia reginae	Bird of Paradise	Petroleum	Unspecified	Shrub
Streptanthus polygaloides	Milkwort	Heavy Metals	Ni	Herbaceous
Suaeda fruticosa	Shrubby Seablight	Other	Salinity	
Suaeda nudiflora	Seepweeds	Other	Salinity	Herbaceous
Tagetes minuta	Upright Marigold, Southern Cone Marigold	Heavy Metals	Cr, Ni, Fe, Mn, Co, Cu, Zn, Pb	
Tagetes patula	French Marigold	Heavy Metals	Cr, Cu, Cd	Herbaceous
Tagetes spp.	Hybrid triploid nugget Marigold	Heavy Metals	As	Herbaceous
Tamarix spp.	Salt Cedar	Heavy Metals	As, Cd, Ca, Cu, Pb, Mn	
Taraxacum officinale	Dandelion	Heavy Metals	Cd	
Taxus baccata	English Yew	Other	Particulate matter	
Taxus media	Anglojap Yew	Other	Particulate matter	
Tecomaria capensis	Cape Honeysuckle	Petroleum	Unspecified	Shrub
Telfairia occidental	Fluted pumpkin	Heavy Metals	Cr	
Thelypteris palustris	Marsh Fern	Heavy Metals	As	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			1) Phytoremediation of RadioÂ¬nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm
Degradation	8–10	North America, South America	Cook and Hesterberg, 2012 Flathman and Lanza, 1998 ITRC PHYTO 3 Nedunuri et al., 2000
Accumulator			(Phyto Textbook) Saebo, A., Popek, R., Nawrot, B., Hanslin, H., Gawronska, H. and Gawronski, S. 2013. Plant species differences in particulate matter accumulation on leaf surfaces. Science of the Total Envrionment 427, pp. 347-354.
Excluder	not available	Italy	Perrino et al., 2012
Tolerance	9+		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Hyperaccumulator	9	Western USA	Baker and Reeves, 2000
Hyperaccumulator			Devi S, Nandwal AS, Angrish R, Arya SS, Kumar N, Sharma SK. Phytoremediation potential of some halophytic species for soil salinity. Int J Phytoremediation. 2016;18(7):693-696. doi:10.1080/15226514.2015.1131229
Accumulator			Devi S, Nandwal AS, Angrish R, Arya SS, Kumar N, Sharma SK. Phytoremediation potential of some halophytic species for soil salinity. Int J Phytoremediation. 2016;18(7):693-696. doi:10.1080/15226514.2015.1131229
Accumulator			1) Nawab J, Khan S, Shah MT, Khan K, Huang Q, Ali R. Quantification of Heavy Metals in Mining Affected Soil and Their Bioaccumulation in Native Plant Species. Int J Phytoremediation. 2015;17(9):801-813. doi:10.1080/15226514.2014.981246 2) Cid CV, Rodriguez JH, Salazar MJ, Blanco A, Pignata ML. Effects of co-cropping Bidens pilosa (L.) and Tagetes minuta (L.) on bioaccumulation of Pb in Lactuca sativa (L.) growing in polluted agricultural soils. Int J Phytoremediation. 2016;18(9):908-917. doi:10.1080/15226514.2016.1156636
Accumulator	Grown as annual	North America, South America	Lin et al., 2010
Potential Accumulators	9–11	Central America	Chintakovid et al., 2008
N/A			1) ITRC. 2004. Phytotechnologies Workshop. Harrisburg, PA. June 9-10, 2004.
Accumulator			Hammami, Hossein, et al. "Weeds Ability to Phytoremediate Cd-Contaminated Soil." International Journal of Phytoremediation, vol. 18, no. 1, 2015, pp. 48–53., doi:10.1080/15226514.2015.1058336.
Accumulator			(Phyto Textbook) Saebo, A., Popek, R., Nawrot, B., Hanslin, H., Gawronska, H. and Gawronski, S. 2013. Plant species differences in particulate matter accumulation on leaf surfaces. Science of the Total Envrionment 427, pp. 347-354.
Accumulator			(Phyto Textbook) Saebo, A., Popek, R., Nawrot, B., Hanslin, H., Gawronska, H. and Gawronski, S. 2013. Plant species differences in particulate matter accumulation on leaf surfaces. Science of the Total Envrionment 427, pp. 347-354.
Tolerance	9–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Tolerant			Padmapriya S, Murugan N, Ragavendran C, Thangabalu R, Natarajan D. Phytoremediation potential of some agricultural plants on heavy metal contaminated mine waste soils, salem district, tamilnadu. Int J Phytoremediation. 2016;18(3):288-294. doi:10.1080/15226514.2015.1085832
Potential Accumulators	3–7	Europe, Eastern North America	Anderson et al., 2010

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Thespesia populnea	Milo	Petroleum	TPH PAH	Tree
Thinopyrum intermedium ssp.	'Oahe' Intermediate Wheatgrass	Heavy Metals	Cd, Zn	Herbaceous
Thinopyrum ponticum	Tall Wheatgrass	Petroleum	TPH	Herbaceous
Thlaspi brachypetalum	Pennycress	Heavy Metals	Zn	Herbaceous
Thlaspi caerulescens	Alpine Pennycress	Heavy Metals	Al, As, Cd, Cr, Co, Cu, Pb, Ni, Zn	Herbaceous
Thlaspi caerulescens (syn. Noccaea caerulescens and Thlaspi tatrense)	Alpine Pennycress	Heavy Metals	Cd, Zn	Herbaceous
Thlaspi capaeifolium ssp. Rotundifolium	Pennycress	Heavy Metals	Zn	Herbaceous
Thlaspi montanum L. var. montanum	Fendler's Pennycress	Heavy Metals	Ni	Herbaceous
Thlaspi ochroleucum	Pennycress	Heavy Metals	Zn	Herbaceous
Thlaspi praecox	Pennycress	Heavy Metals	Zn	Herbaceous
Thlaspi stenopterum	Pennycress	Heavy Metals	Zn	Herbaceous
Thlaspi tatrense	Pennycress	Heavy Metals	Zn	Herbaceous
Thuja occidentalis	Rheingold Arborvitae	Petroleum	Unspecified	Shrub
Tilia coradata Mill.		POP	Particulate Matter, Polycyclic aromatic hydrocarbons , Heavy Metals	
Tithonia diversifolia	Mexican Sunflower Tree Marigold	Heavy Metals	Zn	Herbaceous
Trachelospermum asiaticum	Asian Jasmine	Petroleum	Unspecified	Herbaceous
Tradescantia bracteata	Longbract Spiderwort		Cs, Co, Plutonium, Sr, Tritium, U	
Trifolium hirtum	Rose Clover	Petroleum	TPH	Herbaceous
Trifolium pratense	Red Clover	Petroleum	TPH	Herbaceous
Trifolium repens	White Clover	POP	PCB	Herbaceous
Trifolium repens	White Clover	Petroleum	Fluoranthene Phenanthrene Pyrene TPH PAH	Herbaceous
Trifolium repens	White Clover	Radionuclides	134Cs	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation	8–10	Hawaii	Tang et al., 2004
N/A			Oyler, J. Blue Mountain Superfund Remediation Project, Palmerton, PA. Powerpoint presentation. June 10, 2004. ITRC Phytotechnologies conference
Degradation	3–8	Mediterranean, Asia	Cook and Hesterberg, 2012 Phillips et al., 2009
Hyperaccumulator	Not available	Europe	Baker and Brooks, 1989 Reeves, 2006 Reeves and Brooks, 1983
Hyperaccumulator	6	Western USA, Europe	ITRC PHYTO 3 Rouhi, 1997 Salt et al., 1995
Hyperaccumulator	6	Europe	Baker et al., 2000 Broadhurst et al., 2013 Chaney et al., 2005, 2010 ITRC PHYTO 3 Lasat et al., 2001 McGrath et al., 2000 Reeves, 2006 Rouhi, 1997 Saison et al., 2004 Salt et al., 1995 Schwartz et al., 2006 Simmons et al., 2013, 2014
Hyperaccumulator	6–9	Central Europe	Baker and Brooks, 1989 Rascio, 1977 Reeves, 2006
Hyperaccumulator	6–10	Western USA	Boyd et al., 1994 Phytorem Database Prasad, 2005
Accumulator	Not available	Greece	Kelepertsis and Bibou, 1991 Reeves, 2006
Hyperaccumulator	6	Central Europe	Baker and Brooks, 1989 Reeves, 2006 Reeves and Brooks, 1983
Hyperaccumulator	Not available	Central Europe	Baker and Brooks, 1989, Reeves, 2006
Hyperaccumulator	Not available	Europe	Baker and Brooks, 1989 Reeves, 2006 Reeves and Brooks, 1983
Tolerance	2–7		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator			Popek R, ?ukowski A, Bates C, Oleksyn J. Accumulation of particulate matter, heavy metals, and polycyclic aromatic hydrocarbons on the leaves of Tilia cordata Mill. in five Polish cities with different levels of air pollution. Int J Phytoremediation. 2017;19(12):1134-1141. do i:10.1080/15226514.2017.1328394
Accumulator	9–11	Eastern Mexico	Adesodun et al., 2010
Tolerance	7–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Phytoindicator			1) Phytoremediation of RadioÂ¬nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm
Degradation	8–11	Europe, Asia	Cook and Hesterberg, 2012 Siciliano et al., 2003
Degradation	3+	Europe	Cook and Hesterberg, 2012 Karthikeyen et al., 2012 Muratova et al., 2008
Extraction	3+	Europe	McCutcheon and Spoor, 2003
Degradation	3+	Europe	Banks and Schwab, 1998 Cook and Hesterberg, 2012 Flathman and Lanza, 1998 ITRC PHYTO 3 Johnson et al., 2005 Kulakow, 2006c
Extraction	4+	Europe, Asia	ITRC PHYTO 3 Salt et al., 1992

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Trifolium repens	White Clover	Petroleum	Diesel Fuel, Hydrocarbons, Pb, Polychlorinated Biphenyl (PCB), Polycyclic Aromatic Hydrocarbon (PAH)	
Trifolium repens cv. Huia	Clover	Heavy Metals	As	Herbaceous
Trifolium spp.	Clover	Petroleum	TPH PAH BTEX	Herbaceous
Trifolium spp.	African clover	Pesticides	2,4-D	Herbaceous
Triglochin striata	Three-Rib Arrowgrass	Petroleum	TPH	Herbaceous
Triglochin striata	Streaked Arrow Grass		Petroleum hydrocarbons	Herbaceous
Tripsacum dactyloides	Eastern Gamagrass	Petroleum	TPH PAH	Herbaceous
Tripsacum dactyloides	Eastern Gamagrass	Pesticides	Chlorpyrifos Chlorothalonil Pendimethalin Propiconazole	Herbaceous
Tripsacum dactyloides	Eastern Gamagrass	Heavy Metals	Zn	Herbaceous
Tripsacum dactyloides	Eastern Gamagrass		Anthracene, As, Chloroform, Pb, Perchloroethylene (PCE), Polychlorinated Biphenyl (PCB)	Herbaceous
Triticum aestivum	Wheat	Explosives	RDX	Herbaceous
Triticum aestivum	Wheat	Pesticides	2,4-D Diazinon MCPA Mecoprop	Herbaceous
Triticum aestivum	Wheat	Radionuclides	137Cs, 106Ru, 99Tc, 144Ce	Herbaceous
Triticum aestivum	Wheat	Heavy Metals	Sr	Herbaceous
Triticum aestivum L.	Wheat	Heavy Metals	Ni	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			1) Phytoremediation of RadioÂ¬nuclides. Dushenkov et al. 1998, Negri and Hinchman 2000, Huang et al. 1998, et al. 1997, Negri and Hinchman 2000, Dushenkov et al. 1998. http://rydberg.biology.colostate.edu/Phytoremediation/2000/Lawra/BZ580.htm3) Robison, Diana. â€œPHYTOREMEDIATION OF HYDROCARBON-CONTAMINATED SOIL.â€ UniversityofSaskatchewan, 2003. Web. 18 Feb2011. .
Potential Accumulators	3+	Europe	ITRC PHYTO 3 Speir et al., 1992
Degradation	Varies	Worldwide	Banks, 2006 Cook and Hesterberg, 2012 Parrish et al., 2004 Reynolds, 2006a Reynolds, 2006b Reynolds, 2006c Reynolds, 2006d Reynolds, 2006e
Degradation or hydraulic control	varies	varies	Anderson et al., 1993 ITRC PHYTO 3
Degradation	5–9	North America, Europe	Ribeiro et al., 2013
Accumulator			(Phyto Textbook) Ribeiro, H., Almeida, C., Mucha, A., ad Bordalo, A. 2013. Influence of different salt marsh plants on hydrocarbon degrading microorganisms abundance throughout a phenological cycle. International Journal of Phytoremediation 15 (3), pp. 245-256.
Degradation	4–9	Eastern USA	Cook and Hesterberg, 2012 Euliss, 2004 Euliss et al., 2008
Degradation or hydraulic control	4–9	Eastern USA	Smith et al., 2008
Accumulator	4–9	Eastern USA	Hinchman et al., 1997 ITRC PHYTO 3
N/A			1) Negri, M.C., et al 2003 Root Development and Rooting at Depths, in S.C. McCutcheon and J.L. Schnoor, eds., Phytoremediation: Transformation and Control of Contaminants: Hoboken, NJ, John Wiley & Sons, Inc. p233-262, 912-913 Quinn, J.J., et al 200 Predicting the Effect of Deep-Rooted Hybrid Poplars on the Groundwater Flow System at a Phytoremediation Site: International Journal of Phytoremediation, vol. 3, no. 1, p. 41-60
Degradation	Grown as annual	Asia	Chen et al., 2011 Vila et al., 2007a
Degradation or hydraulic control	Grown as annual	Asia	Anderson, Guthrie and Walton, 1993 ITRC PHYTO 3
Extraction	Grown as annual	Asia	Bell et al., 1988 ITRC PHYTO 3
Accumulator	Grown as annual	Asia	1) Joseph L. Fiegl, Bryan P. McDonnell, Jill A. Kostel, Mary E. Finster, and Dr. Kimberly Gray, Northwestern University 3) Salehi-Lisar SY, Deljoo S, Harzandi AM. Fluorene and Phenanthrene Uptake and Accumulation by Wheat, Alfalfa and Sunflower from the Contaminated Soil. Int J Phytoremediation. 2015;17(12):1145-1152. doi:10.1080/15226514.2015.1045123 4) Zhao H, Guan Y, Qu B. PFCA uptake and translocation in dominant wheat species (Triticum aestivum L.). Int J Phytoremediation. 2018;20(1):68-74. doi:10.1080/15226514.2017.1337066 5) Shtangeeva I, Perämäki P, Niemelä M, Kurashov E, Krylova Y. Potential of wheat (Triticum aestivum L.) and pea (Pisum sativum) for remediation of soils contaminated with bromides and PAHs. Int J Phytoremediation. 2018;20(6):560-566. doi:10.1080/15226514.2017.1405375 6) Qi L, Qin X, Li FM, et al. Uptake and distribution of stable Sr in 26 cultivars of three crop species: oats,
Excluder	2–7	Asia	Massoura et al., 2005

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Triticum spp.	Wheat	Petroleum	TPH	Herbaceous
Tulbaghia violacea	Society Garlic	Petroleum	Unspecified	Perennial
Typha angustifolia	Narrow-leaf cattail		Atrazine	
Typha angustifolia	Narrow Leaved Cattail		Ammonia, Nitrate, N	
Typha latifolia	Cattail	Explosives	TNT	Herbaceous
Typha latifolia	Cattail	Radionuclides	226Ra	Wetland
Typha latifolia	Cattail	Other	Landfill leachate	
Typha latifolia	Cattail	Heavy Metals	As, Pb, Plutonium	Herbaceous
Typha spp.	Cattail	Petroleum	DRO Oil and gasoline Phenol Total suspended solids Biological oxygen demand Chemical oxygen demand	Herbaceous
Typha spp.	Cattail	Chlorinated Sol-vents	Dodecyl linear alcohol ethoxylate, sulfonate and chloride	Herbaceous
Typha spp.	Cattail	Pesticides	Atrazine	Herbaceous
Ulex europaeus	Gorse	Heavy Metals	As	Shrub
Ulmus parvifolia	Chinese Elm	Petroleum	Dioxene	Tree
Urochlea brizantha cvs. Xaraes and Marandu	Palisade grass	Heavy Metals	Zn	Herbaceous
Urtica procera	Tall Nettle	POP	Polychlorinated Biphenyl (PCB), Polycyclic Aromatic Hydrocarbon (PAH)	
Uvaria chamae	Finger root	Petroleum	Petroleum hydrocarbons	Herbaceous
Vaccinium myrtillus	Bilberry	Radionuclides	137Cs	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Degradation	Varies	Asia	Muratova et al., 2008
Tolerance	7–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator/Tolerant			1) Chayapan P, Kruatrachue M, Meetam M, Pokethitiyook P. Effects of Amendments on Growth and Uptake of Cd and Zn by Wetland Plants, Typha angustifolia and Colocasia esculenta from Contaminated Sediments. Int J Phytoremediation. 2015;17(9):900-906. doi:10.1080/15226514.2014.989310 2) (Phyto Textbook) Marecik, R., Bialas, W., Cyplik, P., Lawniczak, L., and Chrzanowski, L. 2012. Phytoremediation Potential of Three Wetland Plant Species Toward Atrazine in EnvFementally Relevant Concentrations. Polish Journal of EnvFemental Studies. 21 (3), pp. 697-702.
N/A			1) Heronswood (2011). www.heronswood.com/index.cfm
Degradation	3–10	North America, Europe, Asia	Nepovim et al., 2005 Vanek et al., 2006
Extraction	3–10	North America, Europe, Asia	ITRC PHYTO 3 Mirka et al., 1996
Accumulator/Tolerant	3–11	North America, Europe, Asia	1) The University of Texas. http://wildflower.org/explore/ 2) April 2003, Jeremiah Knuth, Department of Civil Engineering, Colorado State University.http://rydberg.biology.colostate.edu/Phytoremediation/2003/Knuth/home.htm â€¢ McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Hyperaccumulator	3–9	North America, Europe, Asia	1) http://wikipedia.org/wiki/hyperaccumulators_table_%E2%80%93Â¬Â¬Â¬_3- Pb, plutonium 2) U.S EnvFemental Protection Agency (EPA). Phytoremediation field studies database for chlorinated solvents, pesticides, explosives, and metals. http://www.afcee.af.mil/shared/media/document/AFD-071130-018.pdf (Pb and As source)
Degradation	3–10	North America, Europe, Asia	ITRC PHYTO 3 Kadlec and Knight, 1996 Kadlec and Knight, 1998
Degradation	3–10	North America, Europe, Asia	Anderson et al., 1993 ITRC PHYTO 3
Degradation or hydraulic control	3–10	North America, Europe, Asia	ITRC PHYTO 3 Kadlec and Knight, 1996
Excluder	7–10	Europe	Craw et al., 2007
Degradation	5–9	Asia	Ferro et al., 2013
Accumulator			Nardis BO, Silva EB, Grazziotti PH, Alleoni LRF, Melo LCA, Farnezi MMM. Availability and Zn accumulation in forage grasses grown in contaminated soil. Int J Phytoremediation. 2018;20(3):205-213. doi:10.1080/15226514.2017.1365347
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Accumulator/Tolerant			Anyasi RO, Atagana HI. Profiling of plants at petroleum contaminated site for phytoremediation. Int J Phytoremediation. 2018;20(4):352-361. doi:10.1080/15226514.2017.1393386
Extraction	3+	Western USA	Bunzl and Kracke, 1984 ITRC PHYTO 3

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Vallisneria natans	Straight Vallisneria	Heavy Metals	As	Herbaceous
Vallisneria natans Hara		Heavy Metals	As, Cd, Cu, Ni, Pb, Zn	Herbaceous
Vallisneria spiralis	Tape Grass	Heavy Metals	Cd, Cr, Cu, Pb	Herbaceous
Verbasam olympicum	Mullein	Heavy Metals	Ni	Herbaceous
Veronica spicata	Spiked Speedwell	Petroleum	Unspecified	Perennial
Vetiveria nigritana	Black Vetivergrass	Heavy Metals	Cr, Zn, Pb, Fe, Mn, Mg	Herbaceous
Vetiveria zizanioides	Vetiver Grass	Petroleum	TPH	Herbaceous
Vetiveria zizanioides	Vetiver Grass	Explosives	TNT	Herbaceous
Vetiveria zizanioides	Vetiver Grass	Heavy Metals	Zn, Cd, Cu, Tl	Herbaceous
Vetiveria zizanioides, (syn. Chrysopogon zizanioides)	Vetiver	Pesticides	Endosulfan, Atrazine	Herbaceous
Viburnum awabuki	Viburnum	Heavy Metals	Cu, Pb, Cd	
Viburnum obovatum dentata	Compact Walter's Viburnum	Petroleum	Unspecified	Shrub
Viburnum odoratissimum	Sweet Viburnum	Petroleum	Unspecified	Shrub
Vicia Americana	American Vetch	Inorganic	N, P, Potassium	Shrub
Vicia cracca	Cow Vetch	POP	PCB	Herbaceous
Vicia faba	Broad Bean, Horse Bean	Petroleum	TPH	Herbaceous
Vicia faba	Broad Bean, Horse Bean	Heavy Metals	Al	Herbaceous
Vicia grandiflora	Vetch	Heavy Metals	Al	Herbaceous
Vigna mungo	Black gram	Heavy Metals	Cr	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			Chen G, Liu X, Brookes PC, Xu J. Opportunities for Phytoremediation and Bioindication of As Contaminated Water Using a Submerged Aquatic Plant:Vallisneria natans (lour.) Hara. Int J Phytoremediation. 2015;17(1-6):249-255. doi:10.1080/15226514.2014.883496
Hyperaccumulator			Lu G, Wang B, Zhang C, et al. Heavy metals contamination and accumulation in submerged macrophytes in an urban river in China. Int J Phytoremediation. 2018;20(8):839-846. doi:1 0.1080/15226514.2018.1438354
Accumulator			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Accumulator/Tolerant			Akpinar, Ay?egül, et al. "Ni-Induced Changes in Nitrate Assimilation and Antioxidant Metabolism OfVerbascum OlympicumBoiss.: Could the Plant Be Useful for Phytoremediation or/and Restoration Purposes?" International Journal of Phytoremediation, vol. 17, no. 6, 2014, pp. 546–555., doi:10.1080/15226514.2014.922926.
Tolerance	4–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator			Badejo AA, Sridhar MK, Coker AO, Ndambuki JM, Kupolati WK. Phytoremediation of Water Using Phragmites karka and Veteveria nigritana in Constructed Wetland. Int J Phytoremediation. 2015;17(9):847-852. doi:10.1080/15226514.2014.964849
Degradation	8b-10	India	Danh et al., 2009
Degradation	9–11	India	Das et al., 2010 Markis et al., 2007a Markis et al., 2007b
Accumulator	8–10	India	Danh et al., 2009
Degradation or hydraulic control	9–11	India	Abaga et al., 2012 Marcacci and Schwitzguébel, 2007
Accumulator/Tolerant			Kang W, Bao J, Zheng J, Xu F, Wang L. Phytoremediation of heavy metal contaminated soil potential by woody plants on Tonglushan ancient Cu spoil heap in China. Int J Phytoremediation. 2018;20(1):1-7. doi:10.1080/15226514.2014.950412
Tolerance	6–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Tolerance	8–10		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Extraction	5+	Eurasia	Ficko et al., 2010
Degradation	Grown as annual	Africa, Asia	Radwan et al., 2005 Yateem, 2013
Accumulator			1) Grauer & Horst 1990; McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
N/A			1) McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Tolerant			Padmapriya S, Murugan N, Ragavendran C, Thangabalu R, Natarajan D. Phytoremediation potential of some agricultural plants on heavy metal contaminated mine waste soils, salem district, tamilnadu. Int J Phytoremediation. 2016;18(3):288-294. doi:10.1080/15226514.2 015.1085832

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Vigna radiata	Mung bean	Heavy Metals	Zn, Cu, Cd	Herbaceous
Vinca rose w/ Bacillus megaterium	Vinca	Heavy Metals	Ni	Herbaceous
Viola	Viola	Heavy Metals	As, Antimony, Thalium	Herbaceous
Viola allcharensis G. Beck Viola Asa G. Beck Viola macedonica Boiss. & Heldr. (Balkan)	Viola	Heavy Metals	As	Herbaceous
Viola baoshanensis	Viola	Heavy Metals	Cd	Herbaceous
Viola caliminaria	Viola	Heavy Metals	Zn, (2) Cd, Pb	Herbaceous
Viola spp.	Violet	Heavy Metals	Cd	Herbaceous
Vitex trifolia Linn. var. simplicifolia Cham	SimplePb Chastetree	Heavy Metals	Zn, Pb ,Cu	Tree
Vossia cuspidata (Roxb.) Griff	Hippo Grass	Heavy Metals	Cr, Cu, Pb, Al, Cd, Zn	Herbaceous
Vulpia microstachys (Nutt.) Munro	Small Fescue	Petroleum	TPH PAH	Herbaceous
Washingtonia filifera	California Fan Palm	Petroleum	Unspecified	Tree
Wigandia urens	Stinging Wigandia, Fiberglass Plant	Heavy Metals	Zn	Herbaceous
Wilthania somnifera L. (Dunal)	Indian Ginseng	POP	Lindane HCH	Herbaceous
Wrightia arborea	Woolly Dyeing Rosebay	Heavy Metals	As	Herbaceous
Xanthium strumarium	Rough cocklebur	Other	Salinity	Shrub
Xanthum italicum	Italian Nappola	Heavy Metals	As	Shrub
Yucca hesperaloe parvifolia	Red Yucca	Petroleum	Unspecified	Shrub
Yucca recurvifolia	Yucca	Petroleum	Unspecified	Shrub

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator			Murtaza G, Javed W, Hussain A, Qadir M, Aslam M. Soil-applied Zn and Cu suppress Cd uptake and improve the performance of cereals and legumes. Int J Phytoremediation. 2017;19(2):199-206. doi:10.1080/15226514.2016.1207605
Tolerant			Khan WU, Ahmad SR, Yasin NA, Ali A, Ahmad A, Akram W. Application of Bacillus megaterium MCR-8 improved phytoextraction and stress alleviation of Ni in Vinca rosea. Int J Phytoremediation. 2017;19(9):813-824. doi:10.1080/15226514.2017.1290580
Accumulator			(Phyto Textbook) Baceva, K., Stafilov, T., and Matevski, V. 2013. Bioaccumulation of heavy metals by endemic Viola species from the soil in the vicinity of the As-Sb-Tl Mine "Allchar", Republic of Macedonia. International Journal of Phytoremediation 16, pp. 347-365.
Potential Accumulators	7–8	Macedonia and the Balkans	Baˇceva et al., 2013
Accumulator	Not available	China	Wu et al., 2010 Zhuang et al., 2007
Hyperaccumulator	Not available	Central Europe	Baker and Brooks, 1989 Reeves, 2006
Accumulator of Cd, Hyperaccumulator			1) Institute for EnvFemental Research and education (IERE). (2003 January). Vashon Heavy Metal Phytoremediation Study Sampling and Analysis Strategy (DRAFT). http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf
Accumulator			Shi X, Chen YT, Wang SF, et al. Phytoremediation potential of transplanted bare-root seedlings of trees for Pb/Zn and Cu mine tailings. Int J Phytoremediation. 2016;18(11):1155-1163. doi:10.1080/15226514.2016.1189399
Accumulator			Galal TM, Gharib FA, Ghazi SM, Mansour KH. Phytostabilization of heavy metals by the emergent macrophyte Vossia cuspidata (Roxb.) Griff.: A phytoremediation approach. Int J Phytoremediation. 2017;19(11):992-999. doi:10.1080/15226514.2017.1303816
Degradation	Not available	Western USA	Cook and Hesterberg, 2012 Kulakow, 2006a
Tolerance	8+		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Accumulator			(Phyto Textbook) Cortes-Jimenez, E., Mugica-Alvarez, V., Gonzalez-Chavez, M., Carrillo-Gonzalez, R., Gordillo, M., and Mier, M. 2013. Natural revegetation of alkaline tailing heaps at Taxco, Guerrero, Mexico. International Journal of Phytoremediatio15 (2), pp. 127-141.
Extraction	9+	India	Abhilash et al., 2008
Accumulator			Kumar D, Singh VP, Tripathi DK, Prasad SM, Chauhan DK. Effect of As on Growth, As Uptake, Distribution of Nutrient Elements and Thiols in Seedlings of Wrightia arborea (Dennst.) Mabb. Int J Phytoremediation. 2015;17(1-6):128-134. doi:10.1080/15226514.2013.862205
Accumulator			Devi S, Nandwal AS, Angrish R, Arya SS, Kumar N, Sharma SK. Phytoremediation potential of some halophytic species for soil salinity. Int J Phytoremediation. 2016;18(7):693-696. doi:10.1080/15226514.2015.1131229
Potential Accumulators	Not available	Italy, Mediterranean	Molla et al., 2010
Tolerance	5–11		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)
Tolerance	7–9		Tsao and Tsao, 2003; Fiorenza (BP) and Th omas (Phytofarms), 2004)

LATIN	COMMON	CONTAMINANT CATEGORY	CONTAMINANT	VEGETATION TYPE
Zea Maize	Maize, Common Corn	Heavy Metals	Cu	Herbaceous
Zea Maize	Maize, Common Corn	Heavy Metals	As, Cd, Co, Formaldehyde, Pb, Ni, Polychlorinated Biphenyl (PCB), Polycyclic Aromatic Hydrocarbon (PAH)	Herbaceous
Zea mays	Maize, Common Corn	Petroleum	TPH	Herbaceous
Zea mays	Maize, Common Corn	Chlorinated Solvents	Dodecyl linear alcohol ethoxylate, sulfonate and chloride	Herbaceous
Zea mays	Maize, Common Corn	Explosives	RDX TNT	Herbaceous
Zea mays	Maize, Common Corn	Pesticides	Alachlor Atrazine Diazinon Temik	Herbaceous
Zea mays	Maize, Common Corn	Heavy Metals	Cd	Herbaceous
Zostera marina	Eel Grass	Heavy Metals	Cd	Herbaceous

DEGRADATION TYPE	USDA HARDINESS ZONE	NATIVITY	REFERENCE/SOURCE
Accumulator, Hyperaccumulator			1) (Phyto Textbook) Mukherjee, I., and Kumar, A. 2012. Phytoextraction of endosulfan a remediation technique. Bulletin of EnvFemental Contamination and Toxicology 88 (2), pp. 250-254. 2) Broadhurst CL, Chaney RL, Davis AP, et al. Growth and Cd Phytoextraction by Swiss Chard, Maize, Rice, Noccaea caerulescens, and Alyssum murale in Ph Adjusted Biosolids Amended Soils. Int J Phytoremediation. 2015;17(1-6):25-39. doi:10.1080/15226514.2013.828016 3) Putwattana N, Kruatrachue M, Kumsopa A, Pokethitiyook P. Evaluation of organic and inorganic amendments on maize growth and uptake of cd and zn from contaminated paddy soils. Int J Phytoremediation. 2015;17(1-6):165-174. doi:10.1080/15226514.2013.876962
Accumulator, Hyperaccumulator			1)McCutcheon, S.C., & Schnoor, J.L. (Eds.). (2003). Phytoremediation: Transformation and Control of Contaminants. Hoboken, New Jersey: Wiley-Interscience, Inc. http://www.super-org.net/archive/proposal/plant%20species%20phyto.pdf
Degradation	Grown as annual	North America, Central America	Cook and Hesterberg, 2012 Muratova et al., 2008
Degradation	Grown as annual	USA	Anderson, Guthrie and Walton, 1993 ITRC PHYTO 3
Degradation	Grown as annual	USA	Chen et al., 2011 Vila et al., 2007
Degradation or hydraulic control	4–11	USA	Anderson et al., 1993 ITRC PHYTO 3 Paterson and Schnoor, 1992
Accumulator	3–11	North America	Broadhurst et al., 2014 Stritsis et al., 2014 Thewys et al., 2010 Van Slycken et al., 2013 Witters et al., 2012
N/A			1) McCutcheon & Schnoor 2003, Phytoremediation. New Jersey, John Wiley & Sons pg 891