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INCREMENTAL LANDSCAPE AT A BATON ROUGE OIL REFINERY: TEMPORAL FRAMEWORK FOR PHYTOREMEDIATION IN LOUISIANA CANCER ALLEY

A Thesis

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ABSTRACT

There is a rising need for clear guidance for phytoremediation applications in contaminated land, in anticipation of the severity of the pollution problem in the petrochemical industrial area. Results of a demographic survey of Louisiana neighborhoods adjacent to petrochemical plants indicated that both deep-rooted environmental issues and social inequity are an inherent part of many communities. This research simulated a temporal framework for incremental landscape at a Baton Rouge oil refinery and its surrounding neighborhood using phytoremediation principles with local plants and insects. Through this novel ecosystem, the site will become biodiverse, and community members will be able to explore and learn from a new, healthier landscape with an awareness of the natural process of remediation. This temporal framework can be used by other communities to create healthy neighborhoods.

CHAPTER 1. INTRODUCTION

Louisiana has an abundance of natural resources from the Gulf of Mexico's seabed. Because of this, Louisiana's 18 oil refineries account for nearly one-fifth of the nation's refining capacity and are capable of processing more than 3.3 million barrels of crude oil per day.[1] These refineries along the Mississippi River have existed almost eight decades and has led to a substantial local dependence on petroleum production. [1]One of those refineries, Baton Rouge ExxonMobil, located in North Baton Rouge and the fourth-largest oil refinery[2] has had a significant impact on the economic, social, and political landscape of the area.

The refinery is a double-edged sword. It represents both an opportunity and a threat to the community. Since 1942, the refinery has severely threatened the health of its adjacent neighborhood. In 2013, Louisiana had the fifth-highest cancer death rate in the United States. While the national average is 163 deaths per 100,000, Louisiana's rate was 189 deaths per 100,000.[3] The death rate from cancer in the area dubbed Cancer Alley was higher than the rest of Louisiana. Cancer Alley is an 85 mile stretch of over 200 petrochemical facilities beginning in Baton Rouge[4] stretching past New Orleans and down towards the Gulf Coast. In 2017, the state's Cancer Alley residents sued a chemical plant for nearly 80 years of air pollution.

Though comprising just one-third of the state's population, 80% of Texas's African-American residents live within three miles of a hazardous industrial zoned facility. Studies have found that African Americans living in poverty, are more likely to live near petrochemical plants. Also, they are more exposed to toxic pollutants much higher than more rich whites. [5] For instance, in the North Baton Rouge, the residents are primarily African American and have a 25.4% poverty rate. New Orleans neighborhood near oil refineries are also mainly African American with a 27.3% poverty rate.

There is a growing concern about the future of the oil refinery sites and the adjacent neighborhoods well-being. Some people think that Louisiana should close all the petroleum plants shortly because the oil reserves are almost depleted. Others claim it's

necessary to keep them because of U.S. shale revolution.' According to the United States Department of Energy, the shale boom allowed the United States to increase our production of oil and natural gas significantly. Tight oil formations now account for 36% of total U.S. crude oil production.[6] There is, however, a consensus that the pollution should be urgently addressed in multiple ways. Phytoremediation is one efficient way to clean contaminated land. This method uses vegetation to clean, contain, or prevent contaminants in soils, sediments, and groundwater; It also adds nutrients, porosity, and organic matter. It involves planning, engineering, design[7], take into consideration both regional and cultural practices.

Brownfields first came into existence with the Industrial Revolution in the late 1800s.[8] As a Fourth Industrial Revolution is building on the Third, brownfield land continues to increase in size, but it has the potential to be reused once it is cleaned up.[9] For example, the Gasworks Park in Seattle, Washington, was built on a former coal gasification plant. The site's unique historic structures not only have been preserved but also have been integrated into creative park design. Freshkills Park in Staten Island, New York, employed extensive remediation and design solutions to transform the world's largest landfill to parklands over the next 30 years.[10] These brownfield projects have become important venues for environmental and cultural education by fostering an appreciation of biodiversity and awareness of stewardship.[11] Therefore oil refinery land may have a significant chance of becoming healthier. Calgary in Alberta, Canada, has already transformed their old refinery into a park. The area is safe for recreational use, and the adjacent river's habitat is no longer under threat.[12] Furthermore, many industries are also aware of environmental impact as well. Therefore, Corporate Social Responsibility (CSR) is becoming an integral part of the business[13] primarily in the oil and gas industry regarding sustainable development.

Phytoremediation applications can play a significant role, providing a more sustainable choice for remediation when combined with short - and long-term land planning. This is attributed to the fact that primary plant functions can contribute to remediation

mechanisms; in the processing of several essential resources including energy, nutrients, and water, contaminants can get taken up, transformed or broken down.[14] To date, most studies of phytoremediation have been limited to technologies[15] and single plant species[16]. A few studies also have investigated the physical habitat restoration of the petroleum-contaminated wetlands. Some phytoremediation studies, like the one performed by Effendi, Hefni, et al. (2017) have examined the factors associated with specific contaminants[17] found that plant species grew better in crude oil contaminated water but are geographically restricted to the Middle East area. My study, therefore, proposes incremental landscape at a Baton Rouge oil refinery with a temporal framework to create a novel ecosystem.[18]

Other studies have focused on growth response and phytoremediation ability of individual species for specific contaminants. For example, Wang, Jun, et al.(2011), who used reeds to cleanse diesel contaminant, found that reeds could tolerate the applied diesel concentration and they could effectively promote the degradation rate of diesel in the soil.[19] Schreurs, Eloi, et al.(2011), also proposed GIS can be a useful tool to assess the biomass potential from phytoremediation of contaminated agricultural land in Belgium.[20] Lewis, Mary-Cathrine, et al.(2013), demonstrated that the long-term effects of phytoremediation on soils contaminated by crude oil and diesel fuel in interior Alaska. Fifteen years later, they found that increased TPH disappearance appeared to be associated with increased numbers of trees and shrubs such as willow, birch, white spruce, and balsam poplar, all native to the region, which had colonized the site. [21] While these and other studies have provided valuable information about phytoremediation, most of the studies have been undertaken not in Louisiana. Kate and Niall (2017) argued that caution should be exercised when generalizing findings and applying them to other regions because of differences in environmental values such as soil, weather, temperature, and different contaminants.[22]

Therefore, more information regarding phytoremediation in Louisiana is needed, not only to create novel ecosystems but also enhance the quality of life in Louisiana’s Cancer Alley. The purpose of this study is to design a temporal framework for

incremental landscape in a Baton Rouge oil refinery by applying phytoremediation technology across the 2300-acre site. The results of this study can provide necessary information to establish strategies to improve environmental quality in Louisiana's Cancer Alley. Information obtained from ecosystem studies can be useful for the other planners to enhance environmental quality, which applies to the other oil refineries in Louisiana's Cancer Alley and helps improve the environment and health of residents who are currently suffering from pollution.

1.1. Study area

This study area is a Baton Rouge Oil Refinery in Louisiana's Cancer Alley. Table 1. summarizes the characteristics of the refinery regarding location, size, and cumulative releases of toxic substances. Within the study site, clusters are bounded by certain types of contaminants and infrastructures. ExxonMobil's Baton Rouge Refinery, established in 1909, is the fourth-largest oil refinery in the United States with an output capacity of 502,500 barrels per day. The size of the refinery is 2,100 acres (8.5 km^3). Today, Baton Rouge Oil Refinery is the most significant employer in the parish, employing about 4,400 with additional contractors, according to the company's website. The operation pays more than $100 million in taxes each year. [23]

Table 1. Summary of the Baton Rouge oil refinery features

	Baton Rouge Oil Refinery
Location	Baton Rouge, Louisiana, United States
Size	2,100 acres (8.5 km^3)
Owner	Exxon Mobil
Year Opened	1909
Number of Employees [a]	4450
Production [a]	502,500 barrels/day of crude oil capacity (4th largest in the U.S.)

[a] Baton Rouge Refinery ExxonMobil Refining and Supply (2016).

1.2. Site inventory - Regional

1.2.1. Location

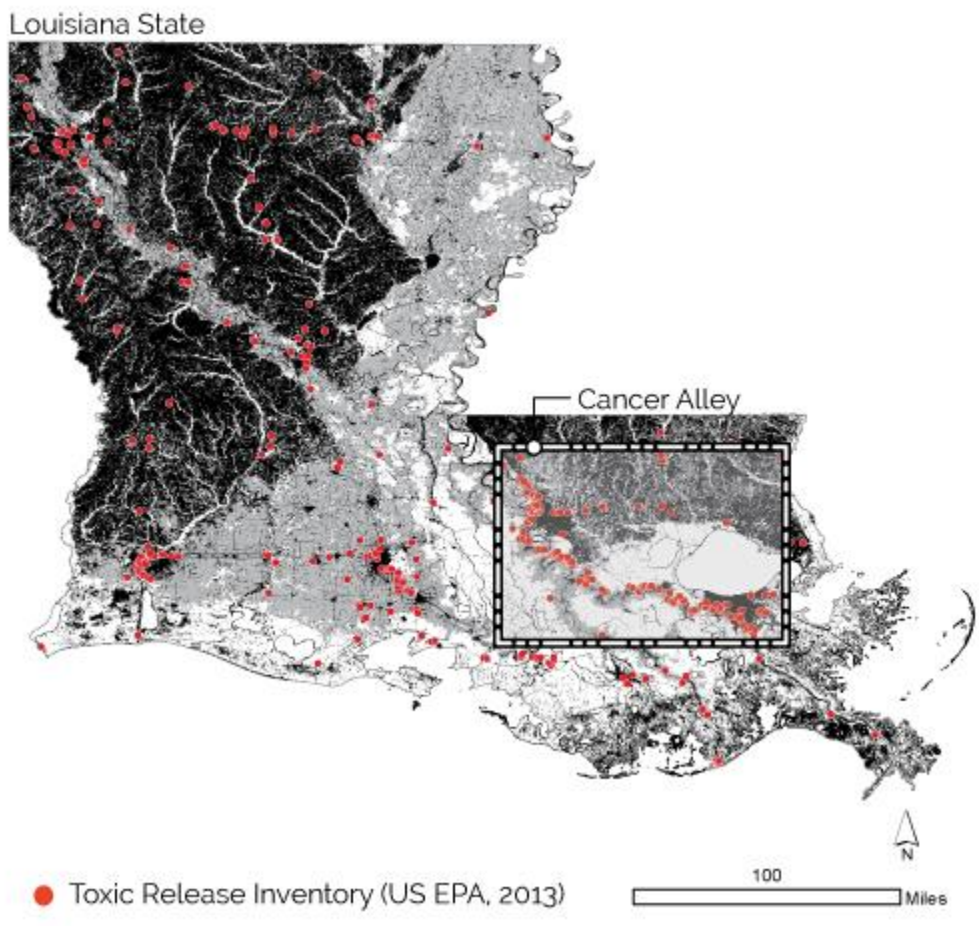


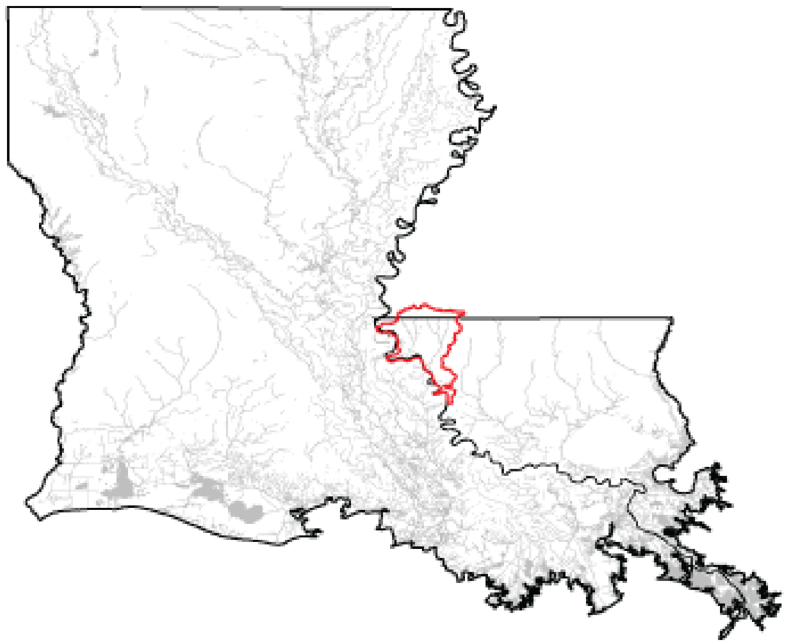
Figure 1. The Geographic Location of Cancer Alley in Louisiana

Figure 1. shows geographic location of ‘Cancer Alley’ in Louisiana.

1.2.2. Pollution – Water quality

At the same time, however, the refinery is a chief cause of Baton Rouge environmental pollution. Figure 2. summarizes the water quality of the Bayou Sara-Thompson watershed and the Monte Sano Bayou where the study area is located. One of the watersheds in the bottom 10% in the U.S. is part of the study area including six impaired waterbodies. This is because the chemical corridor in the watershed has released lots of contaminants which include ammonia, Kjeldahl nitrogen, silica, and Phosphorous.

Figure 2. Summary of the Bayou Sara-Thompson Watershed Quality Assessment

	Bayou Sara-Thompson Watershed
Location	 Geographic Location of Bayou Sara-Thompson Watershed
Percentage of Surface Waters with Impaired [a]	90 -100% (Dirtiest/Worst Watersheds)
Number of Impaired Waterbodies [a]	6 (Over National Average)
Water-quality constituent (2011 – 2016) [b]	NH_3(ammonia), NO_3 +NO_2 (nitrate plus nitrite), OP(orthophosphate), SI(silica), TKN (Kjeldahl nitrogen), TN (Nitrogen), TP(Phosphorus)

[A] U.S. EPA Watershed Health Index (2016).
[b] USGS Nutrient and pesticide data collected from the USGS National Water Quality Network and previous networks, 1963-2016 (2017).

1.2.3. Natural Resources – Wetlands

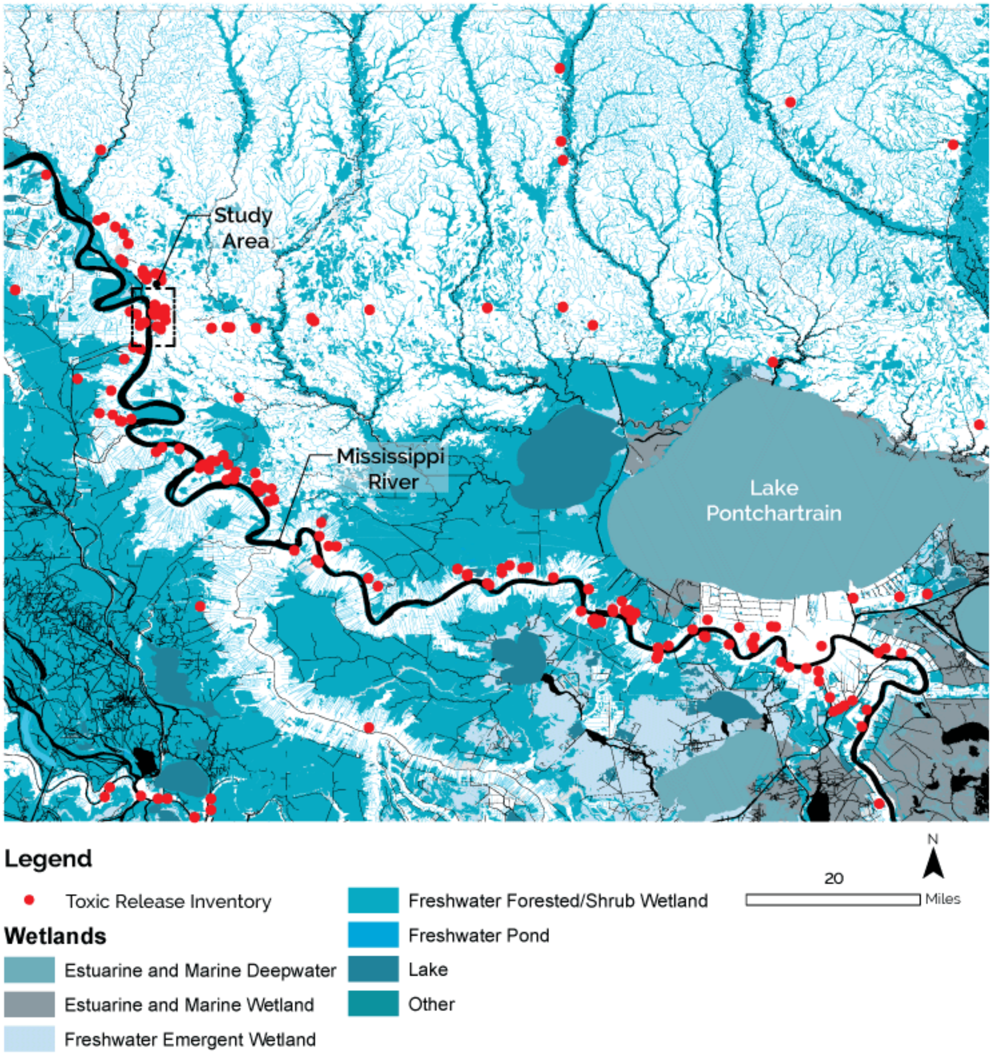


Figure 4. Wetlands in Cancer Alley

Figure 4. shows that Louisiana has the most extensive wetlands in the U.S., from extensive coastal marshes that provide a critical buffer against hurricanes to dark bottomland swamps along Gulf-bound rivers. [a] [b] Louisiana's wetlands today represent about 40 percent of the wetlands of the continental United States, but 80 percent of the losses. [c]

[a] Service, U.S. Fish, and Wildlife. "Upper Ouachita National Wildlife Refuge." *Official Web Page of the US Fish and Wildlife Service*, www.fws.gov/upperouachita/.
[b] "Information." *Information | Louisiana Department of Wildlife and Fisheries*, www.wlf.louisiana.gov/wildlife/information.
[c] Shirley, Jolene S. "Louisiana Coastal Wetlands: A Resource At Risk." *Louisiana Coastal Wetlands: A Resource At Risk - USGS Fact Sheet*, pubs.usgs.gov/fs/la-wetlands/.

1.2.4. Natural Resources – Cultivated Crops

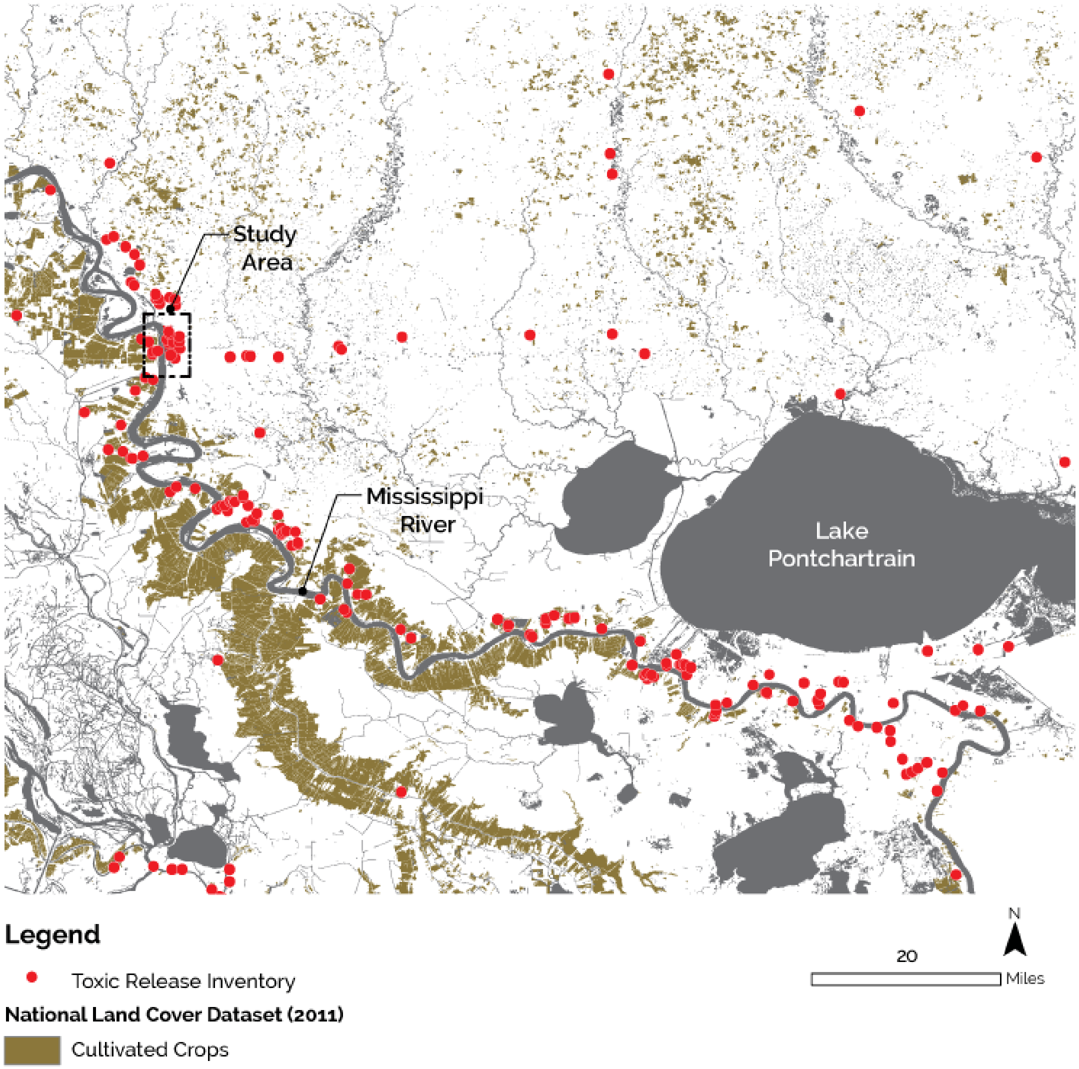


Figure 5. Cultivated Crops in Cancer Alley

Figure 5. shows that Louisiana's abundant natural resources have supported the development of its economy. The fertile soil of Louisiana has produced bountiful harvests since the Native Americans first planted corn. Agriculture today has shifted from the small farms and plantations of the past to substantial agribusiness systems. [a] Sugarcane is the leading farm product in Louisiana. Other important crops are rice, soybeans, and corn for grain. [b]

[a] "Information." *Information | Louisiana Department of Wildlife and Fisheries*, www.wlf.louisiana.gov/wildlife/information.

[b] "2017 STATE AGRICULTURE OVERVIEW." *USDA/NASS 2017 State Agriculture Overview for Louisiana*, www.nass.usda.gov/

1.2.5. Natural resources – Forest

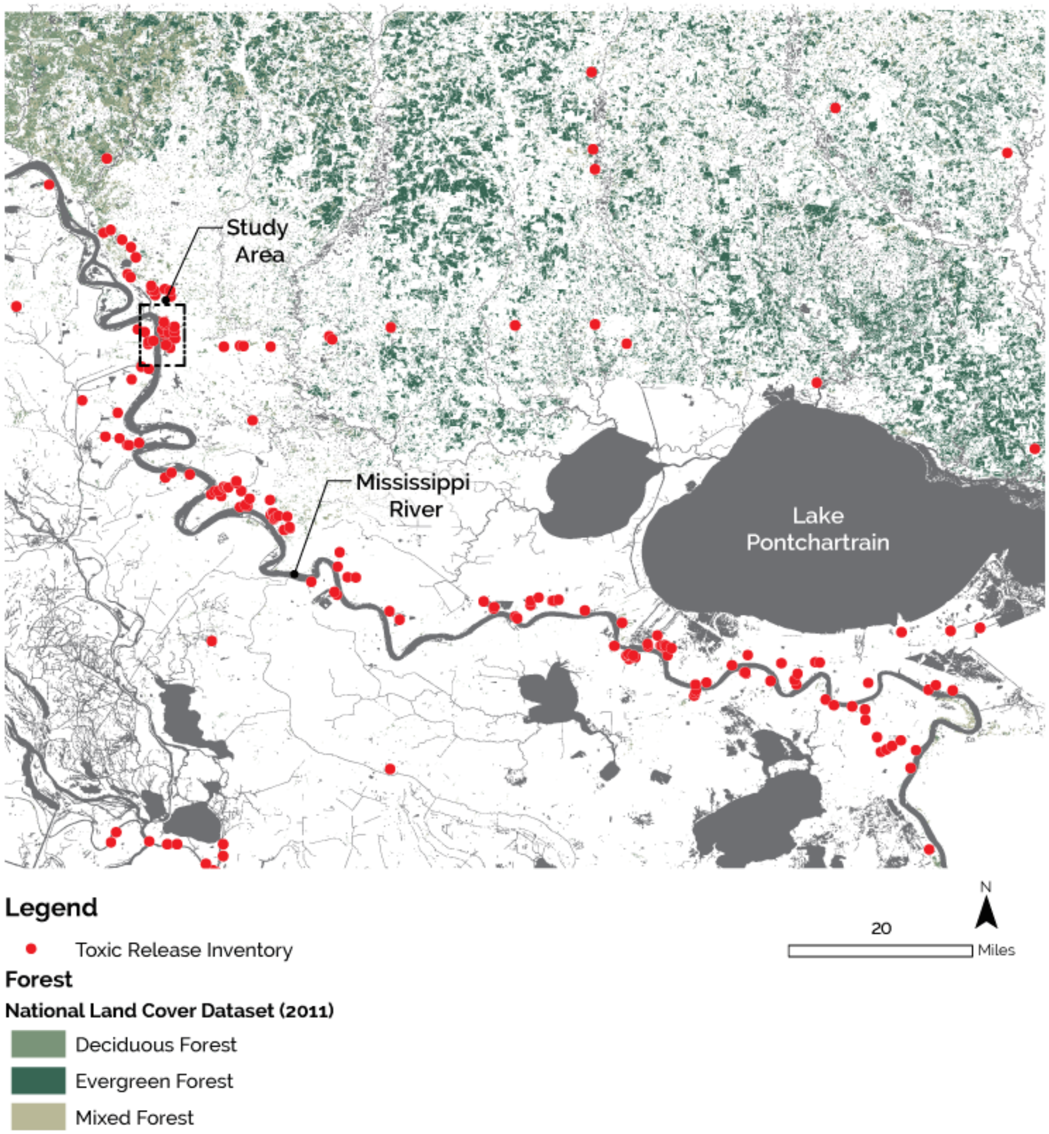


Figure 6. Forest in Cancer Alley

Figure 6. shows that Louisiana's forestlands cover 48% of the state's area or 13.8 million acres. Private, non-industrial landowners own 62 percent of the state's forestland, forest products industries own 29 percent, and the general public holds 9 percent. Louisiana's forests provide a multitude of other benefits, including clean air and water, wildlife habitat, recreational opportunities and scenic beauty. [a]

[a] "Department of Agriculture and Forestry, State of Louisiana - Mike Strain DVM, Commissioner." *Department of Agriculture and Forestry Forestry Comments*, www.ldaf.state.la.us/forestry/

1.2.6. Vacant Lots

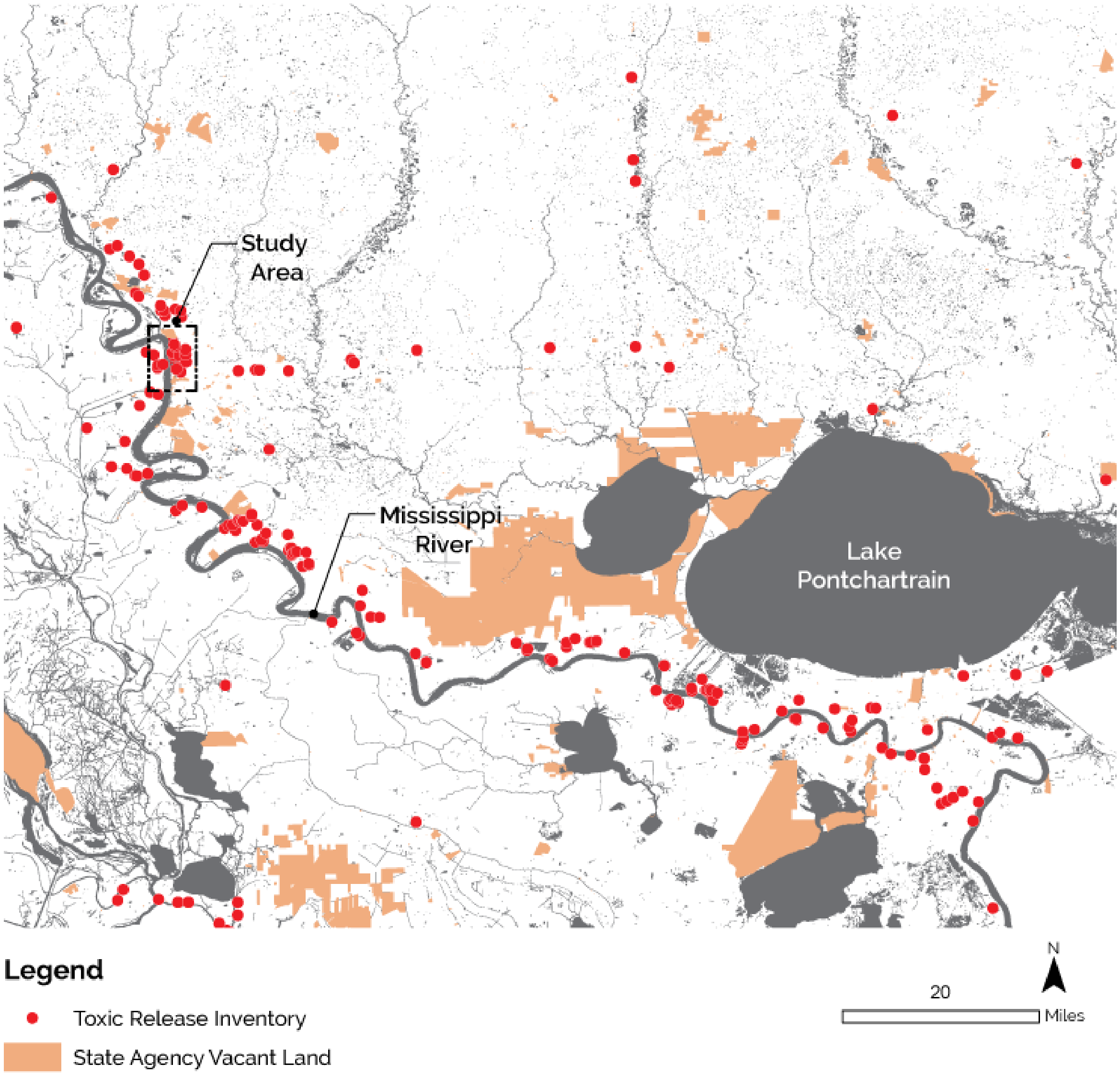


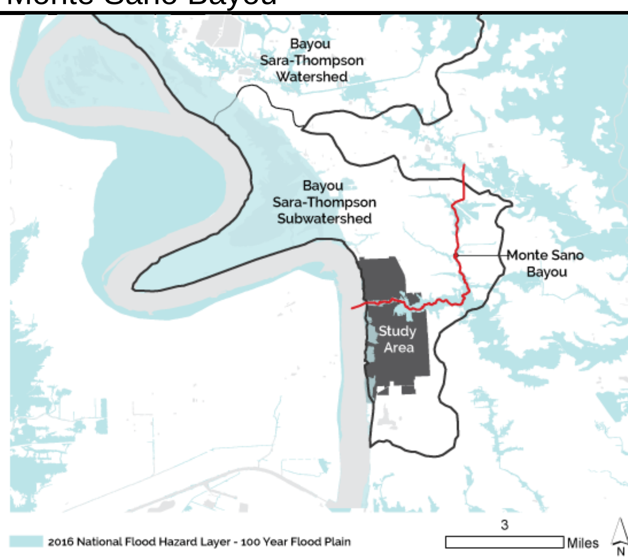
Figure 7. Vacant Lots in Cancer Alley

According to the Figure 7., EPA designated Superfund sites in Louisiana to clean-up the nation's uncontrolled hazardous waste sites along Mississippi River. [a] Also, Along the entire Lake Pontchartrain frontage of the project there shall be reserved and dedicated forever by the government for public parks, parkways, playgrounds, aviation fields, places of amusement, and beach purposes.

[a] *Louisiana State Legislature*, legis.la.gov/legis/Law.aspx?d=95507.
[b] "Cleanups in Louisiana." *EPA*, Environmental Protection Agency, 31 Jan. 2018, www.epa.gov/la/cleanups-louisiana#sites**.**

1.3. Site inventory - On-Site

Monte Sano Bayou impairment, in particular, was caused by dissolved oxygen, fecal coliform, lead and chlorine which primarily results from chemical products. After an accident at Exxon in 2012, more than 31,000 pounds of the cancer-causing chemical benzene leaked. According to residents and reports, many vomited while others suffered breathing problems, tremors, and burning eyes. [24] According to the Louisiana Department of Environmental Quality data, there were 331 industrial accidents in 2013. The department reported that the accidents released around 200,000 pounds of hydrogen cyanide, 200,000 pounds of carbon monoxide and more than 800,000 pounds of sulfur dioxide into the air. [24] The impact of industrial byproducts negatively influenced on the North Baton Rouge community. Summary of the Monte Sano Bayou Quality Assessment is as follows in Figure 8.

	Monte Sano Bayou
Location [a]	
Causes of Impairment	Dissolved Oxygen (2016, 2014, 2012, 2010, 2008, 2006) Fecal Coliform (2012, 2010) Lead (2012, 2010) Chlorine (2010, 2008, 2006, 2004, 2002)

[a] U.S. EPA 305(b) Assessed Waterbody History Report (2016).

Figure 8. Summary of the Monte Sano Bayou Quality Assessment

1.3.1. Greenhouse Gas Emissions from Large Facilities [a]

Gas Emissions are in the study area as follows in Table 2.

Table 2. Greenhouse Gas Emissions from Large Facilities

	HONEYWELL INTERNATIONAL INC - BATON ROUGE PLANT	EXXONMOBIL BATON ROUGE REFINERY AND CHEMICAL PLANT	Air Products and Chemicals, Inc.	FORMOSA PLASTICS CORPORATION LOUISIANA	EAST WEST COPOLYMER LLC - BATON ROUGE PLANT	Eco Services Baton Rouge Site	Total
Total Facility Emissions in metric tons CO2equivalent (mt CO2e) (AR4 GWPs, excluding Biogenic CO2)	108,274	6,213,241	894,838	372,371	61,491	51,103	**7,701,318**
Emissions by Gas in mt CO2e (AR4 GWPs)							
Carbon Dioxide (CO_2)	16986	6,182,582	894,838	372025	61427	51050	**7578908**
Methane (CH_4)	8	15,437	0	158	29	24	**15656**
Nitrous Oxide (N_2O)	10	15,222	0	188	35	29	**15484**
Hydrofluorocarbons (HFCs)	91204	0	0	0	0	0	**91204**
Very Short-lived Compounds	66	0	0	0	0	0	**66**
Emissions by Source/Process in mt CO2e (AR4 GWPs, excluding Biogenic CO2)							
Stationary Combustion	17004	4,431,877	0	334093	61491	51103	**4895568**
Fluorinated GHG Production	91271	0	0	0	0	0	**91271**
Petrochemical Production	0	36,055	0	38277	0	0	**74332**
Petroleum Refining	0	0	0	0	0	0	**0**
Hydrogen Production	0	0	894,838	0	0	0	**894838**
Information on Stationary Combustion							
Types of Fuels Used	Natural Gas	Distillate Fuel Oil No. 2, Fuel Gas, Motor Gasoline, Natural Gas, Propane	Natural Gas	Natural Gas	Natural Gas	Natural Gas	**N/A**
Measurement Methods Used	Mass Balance	Mass Balance	Mass Balance	Mass Balance	Mass Balance	Mass Balance	**N/A**
Number of equipment groupings	1	14	1	10	1	1	**28**
Information on Petroleum Product Supply							
Net GHG quantity (in MT CO_2e)	0	77,118,287	0	0	0	0	**77,118,287**
Information on Petrochemical Production							
Types of Units		Flare, Petrochemical process ui		Petrochemical process unit			
Number of units		5	0	1	0	0	**6**
Information on Petroleum Refining							
Types of Units	N/A	Catalytic Reforming Unit, Delayed Coking Unit, Process Vent, Sulfur Recovery Plant	N/A	N/A	N/A	N/A	**N/A**
Number of units	0	10	0	0	0	0	**10**

[an] *EPA*, Environmental Protection Agency, ghgdata.epa.gov/ghgp/main.do.

1.3.2. Toxic Release Inventory

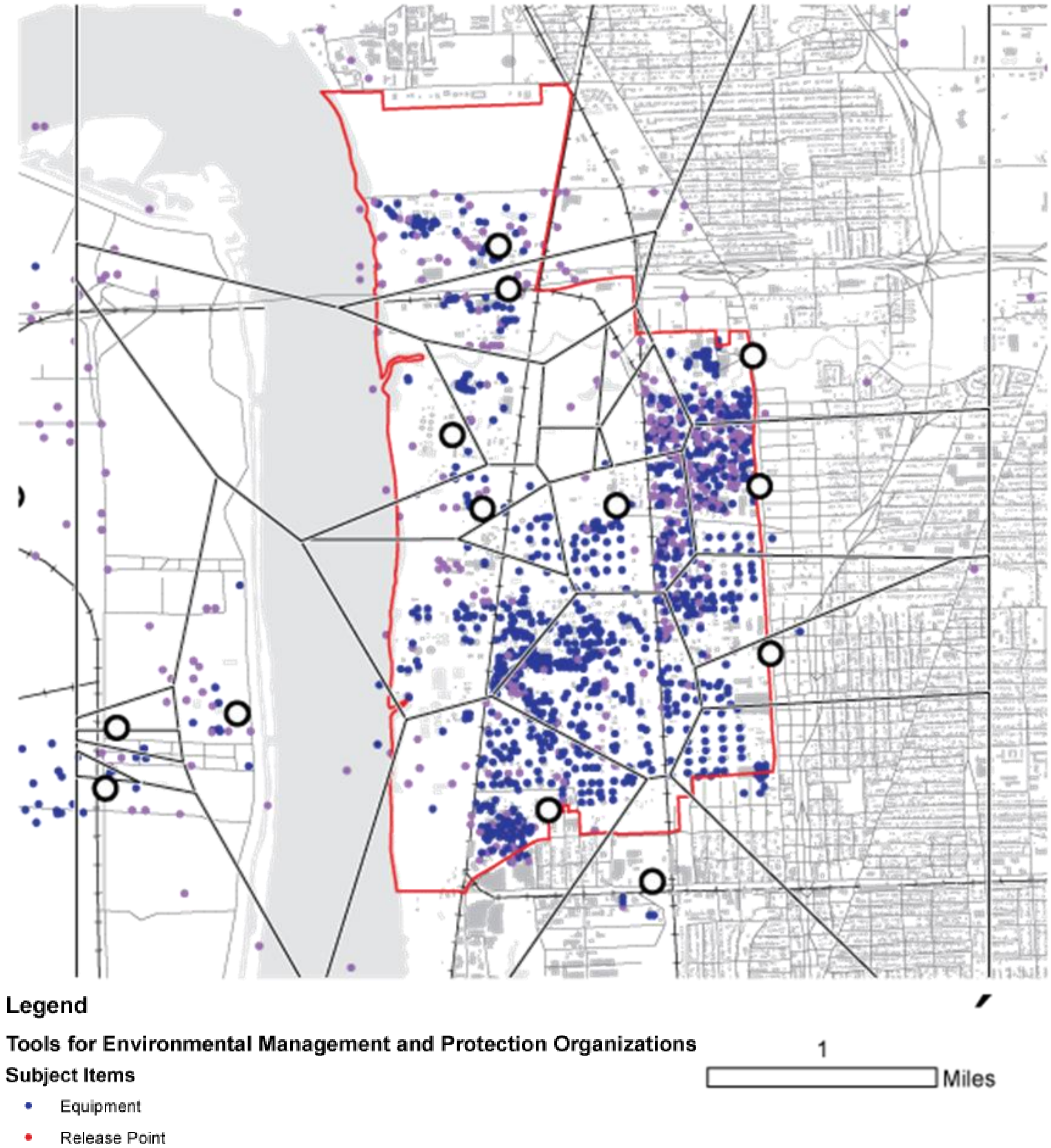


Figure 9. Toxic Release Inventory in Study Area

According to the EPA Toxic Release Inventory map in 2013 (Figure 9.), the study area is highly contaminated by equipment and release point with various pollutants. There is a tendency that release points have highly polluted inorganic materials so that those areas are relatively difficult to clean up than regions with organic pollutants.

1.3.3. Flood Hazard / Slope

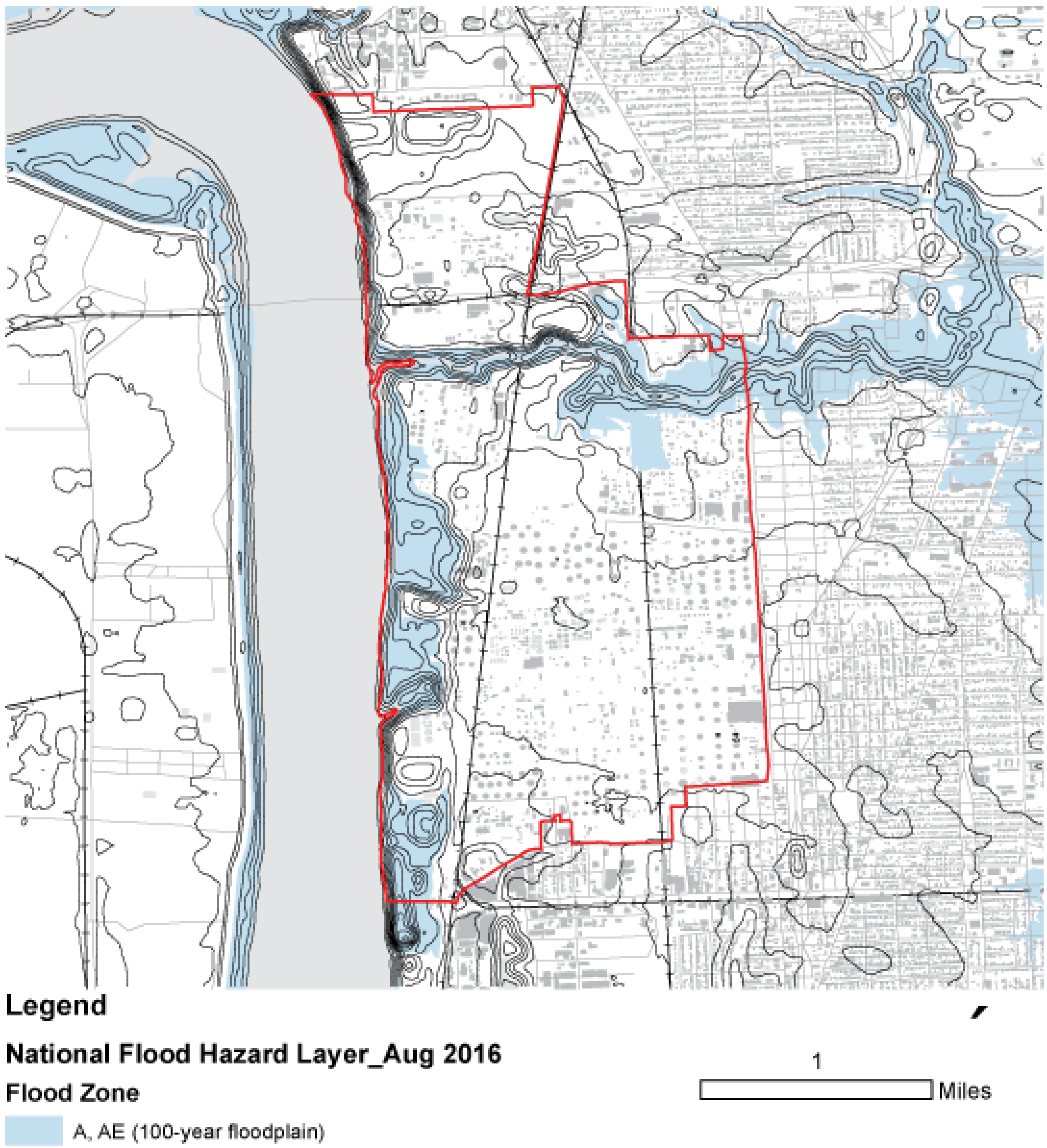


Figure 10. FEMA National Flood Hazard Map in Study Area

Through FEMA's flood hazard mapping program, Risk Mapping, Assessment and Planning (MAP), FEMA identifies flood hazards, assesses flood risks. Figure 10. shows that within the study area, there is flood hazard area along the Monte Sano Bayou.

1.3.4. Soil

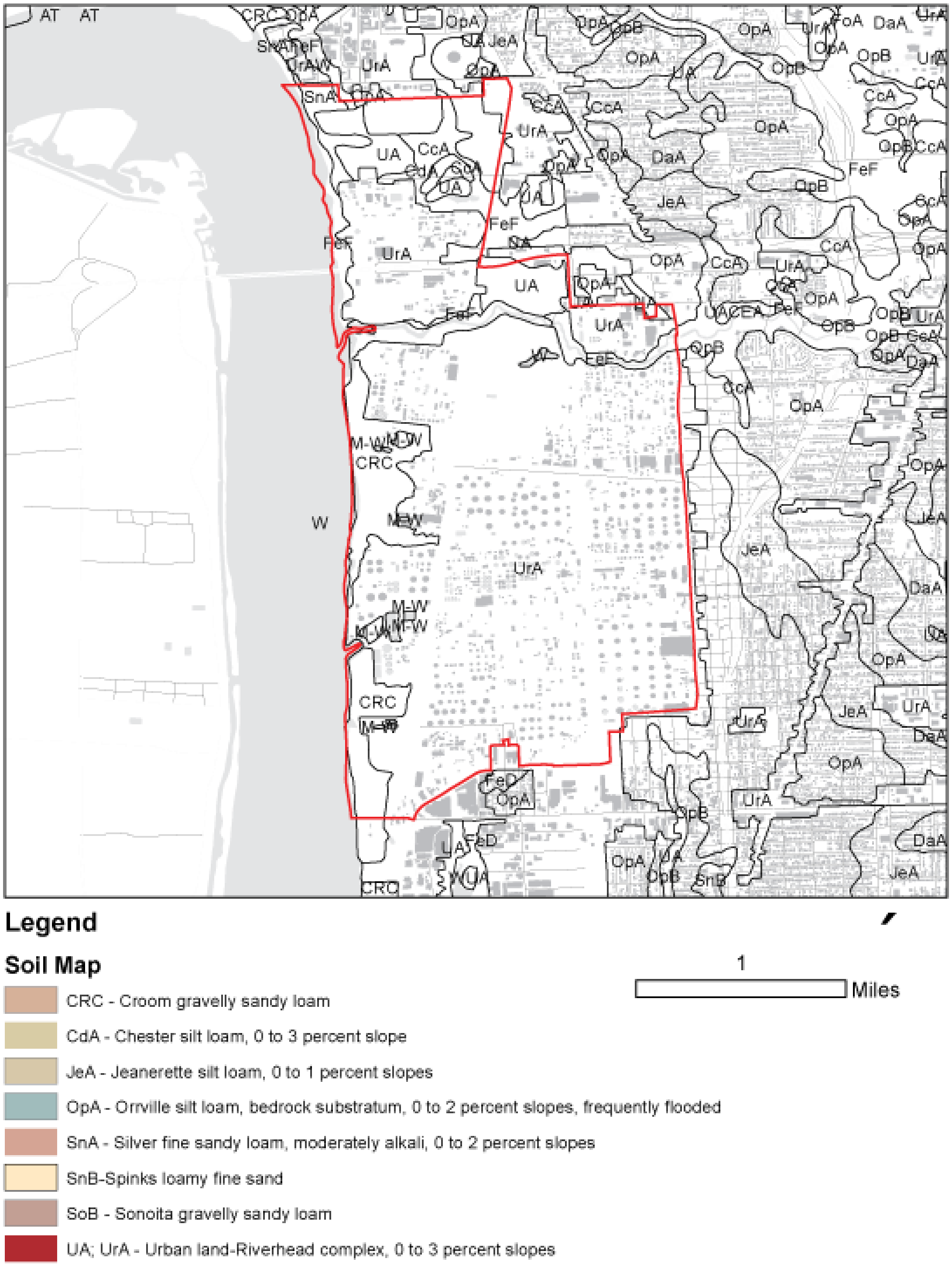


Figure 11. Soil Map in Study Area

Figure 11. shows that study area soil is composed of the highly Urban land-Riverhead complex. Overall slopes are 0 to 3 percent.

CHAPTER 2. METHODS

The study attempted to investigate which plant communities can efficiently remediate contaminants in an oil refinery and to demonstrate a proper temporal framework and expectation with the design. A detailed research flowchart is illustrated in Figure 12.

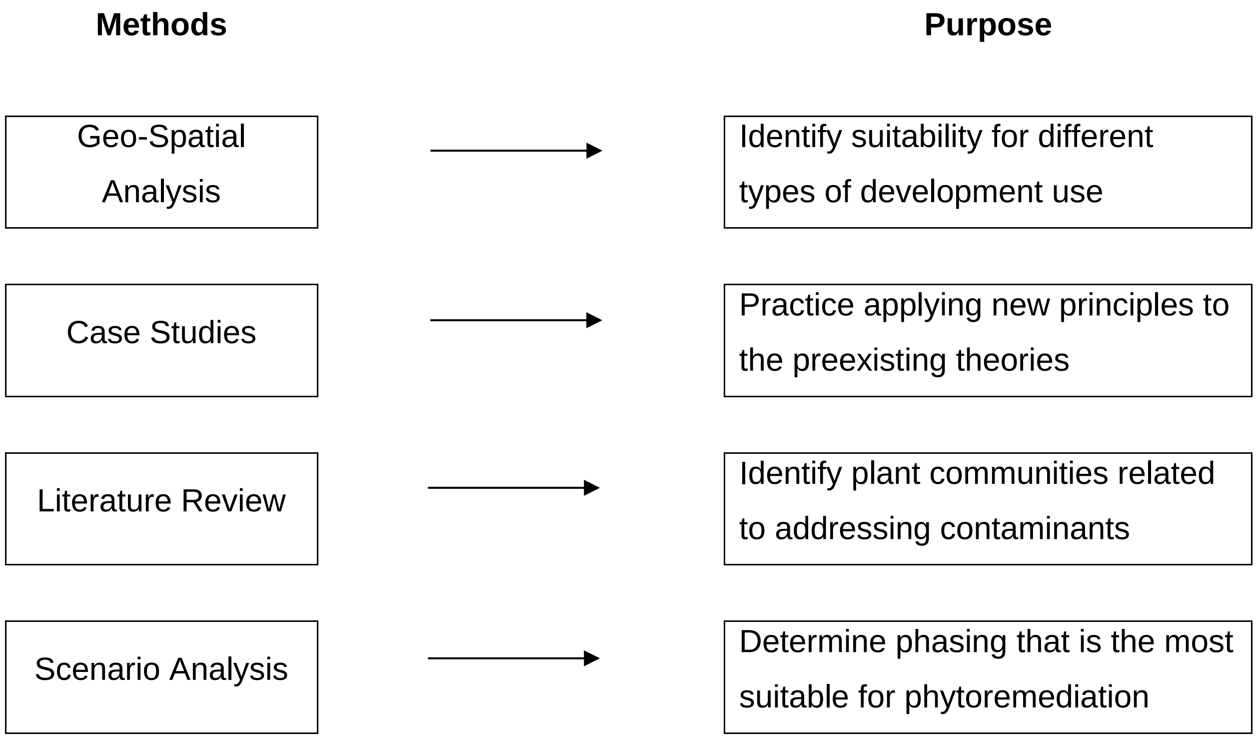


Figure 12**.** Research Flow Chart

The Weighted Overlay tool applies one of the most used approaches for overlay analysis to solve multicriteria problems such as site selection and suitability models. In a weighted overlay analysis, each of the general overlay analysis steps is followed.[26]

As with all overlay analysis, in weighted overlay analysis, you must define the problem, break the model into sub-models, and identify the input layers.

Since the input criteria, layers will be in different numbering systems with different ranges, to combine them in a single analysis, each cell for each criterion must be reclassified into a common preference scale such as 1 to 10, with ten being the most vulnerable. [26]

The tool combines the following steps:

1) Reclassifies values in the input rasters into a common evaluation scale of suitability or preference, risk, or some similarly unifying scale
2) Multiplies the cell values of each input raster by the rasters weight of importance
3) Adds the resulting cell values together to produce the output raster [26]

2.1. GeoSpatial Analysis: Weighted Overlay Analysis

Figure 13. demonstrates what kind of criteria should be used to create useful vulnerability map for further planning and design process.

Figure 13. Weighted Overlay Analysis Flow Chart

The steps for creating vulnerability map on-site are as follows. First, for the proper evaluation scale increments, buffer zones around petrochemical infrastructures should be set. In this scale, the least vulnerable area is scale = 1, and the most vulnerable area is scale =9. Secondly, add input rasters. Infrastructures such as pipelines, crude oil facilities, petrochemical equipment, source, release points, fugitives, industrial facilities, road, and rail were added. Thirdly, Set the scale values as follows (Figure 14.). The cell values for each input raster in the analysis are assigned values from the evaluation scale. Then, change the default values assigned to each cell according to vulnerability. For example, High scale value was given on closer area from the infrastructure. This is because those areas would pollute more than the further ones. Lastly, assign weights to input rasters. Each input raster can be weighted, or assigned a percentage influence, based on its importance. The total influence for all rasters must equal 100 percent.

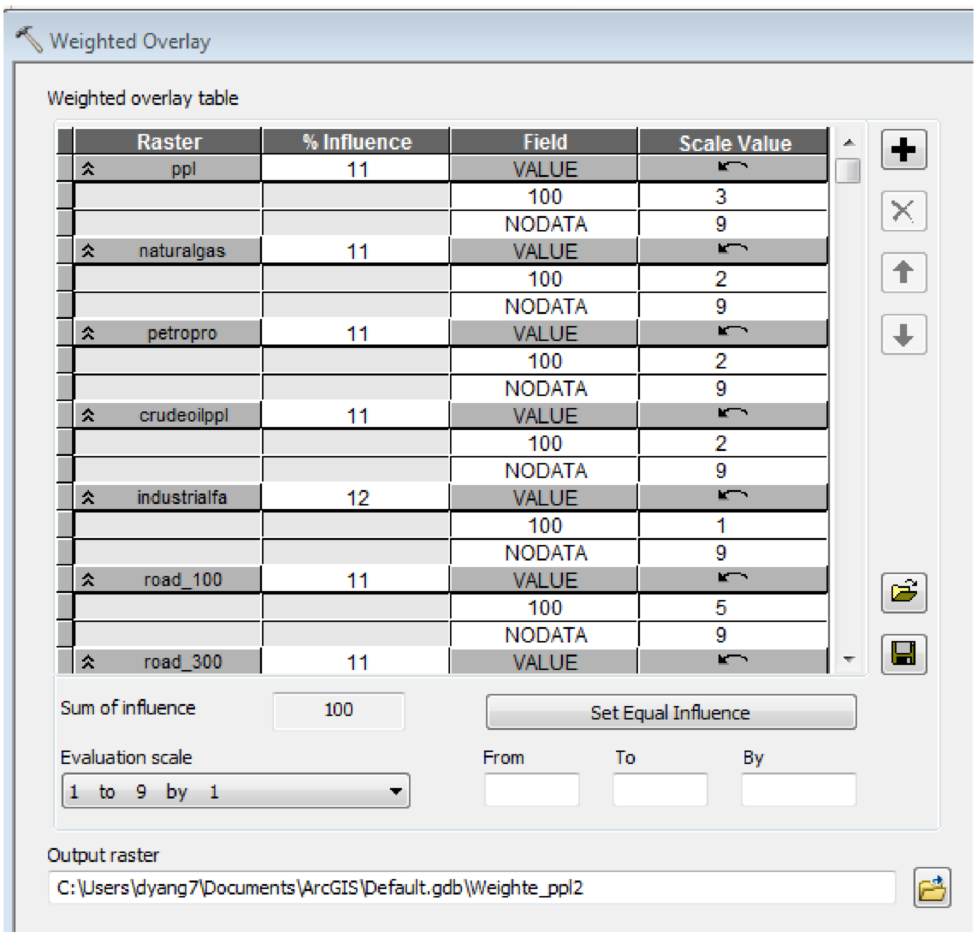


Figure 14**.** Weighted Overlay Steps

2.1.1. Chemical Infrastructure Weighted Overlay Analysis

Figure 15. indicates the result of the chemical infrastructure weighted overlay analysis. There is a tendency that highly contaminated areas are distributed within fugitive infrastructures with inorganic pollutants which is also part of Cobalt Compounds area.

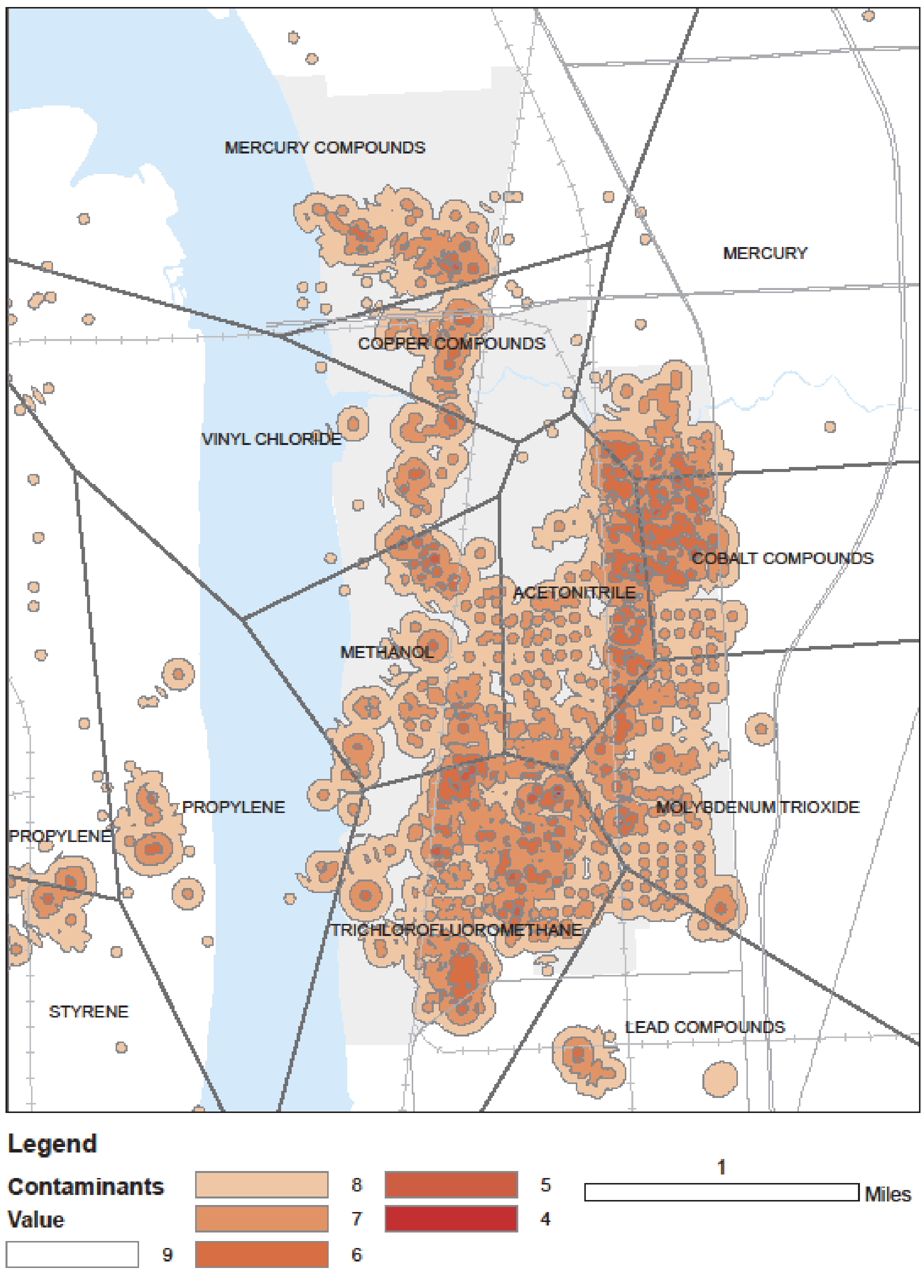


Figure 15. Chemical Infrastructure Weighted Overlay Analysis
with Contaminants Voronoi Diagram

2.3.2. Transportation Weighted Overlay Analysis

Figure 16. indicates the result of the transportation infrastructure weighted overlay analysis. Herbicides are used along rail corridors to control vegetation growth. They often include inorganic pollutants and salts, which build up over time.

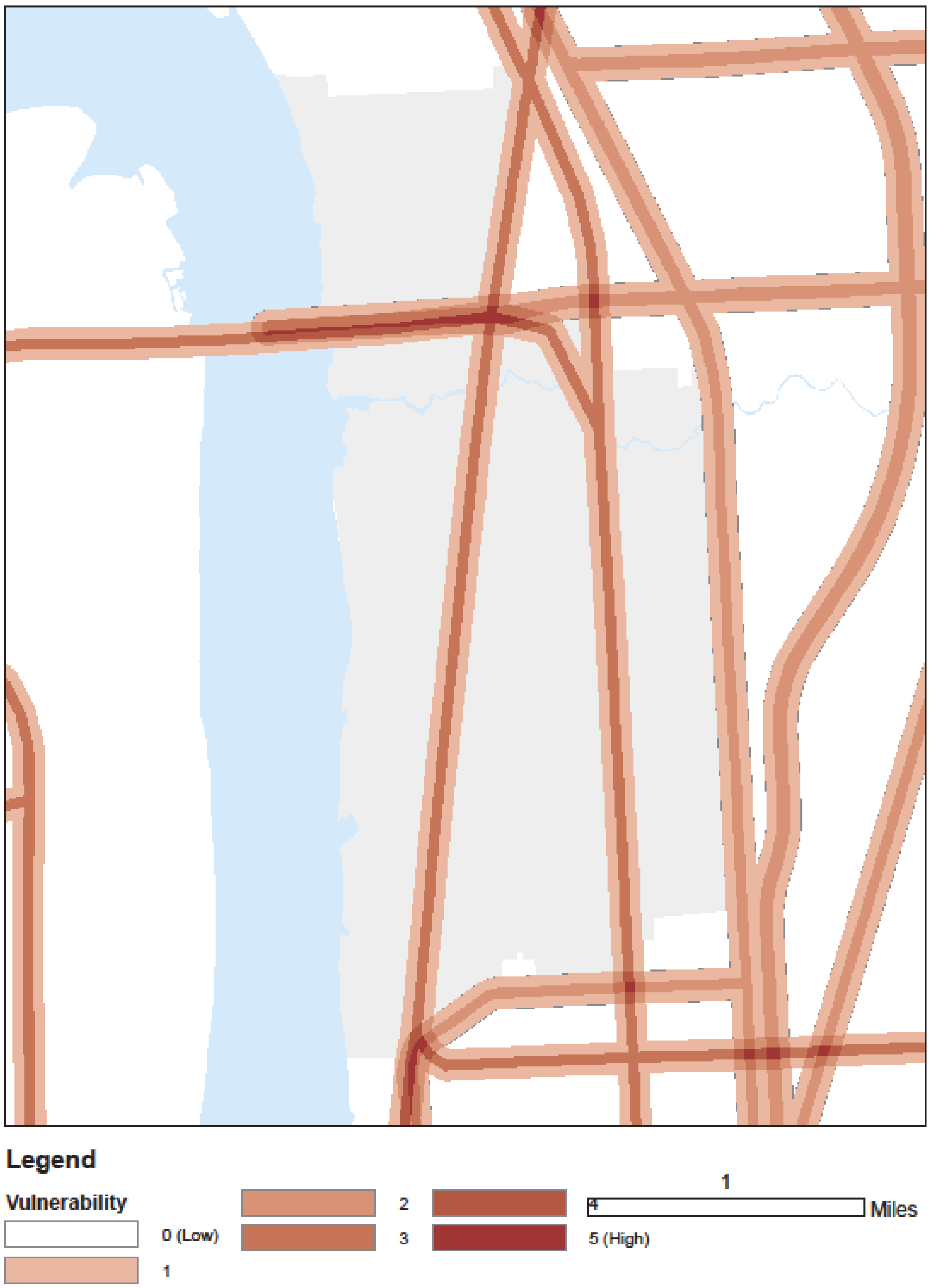


Figure 16. Transportation Weighted Overlay Analysis

2.3.3. Contamination Overlay Map

Figure 17. indicates which area is the most contaminated. There is a tendency that highly contaminated areas are along the rail corridor as well as 100ft within fugitive infrastructures.

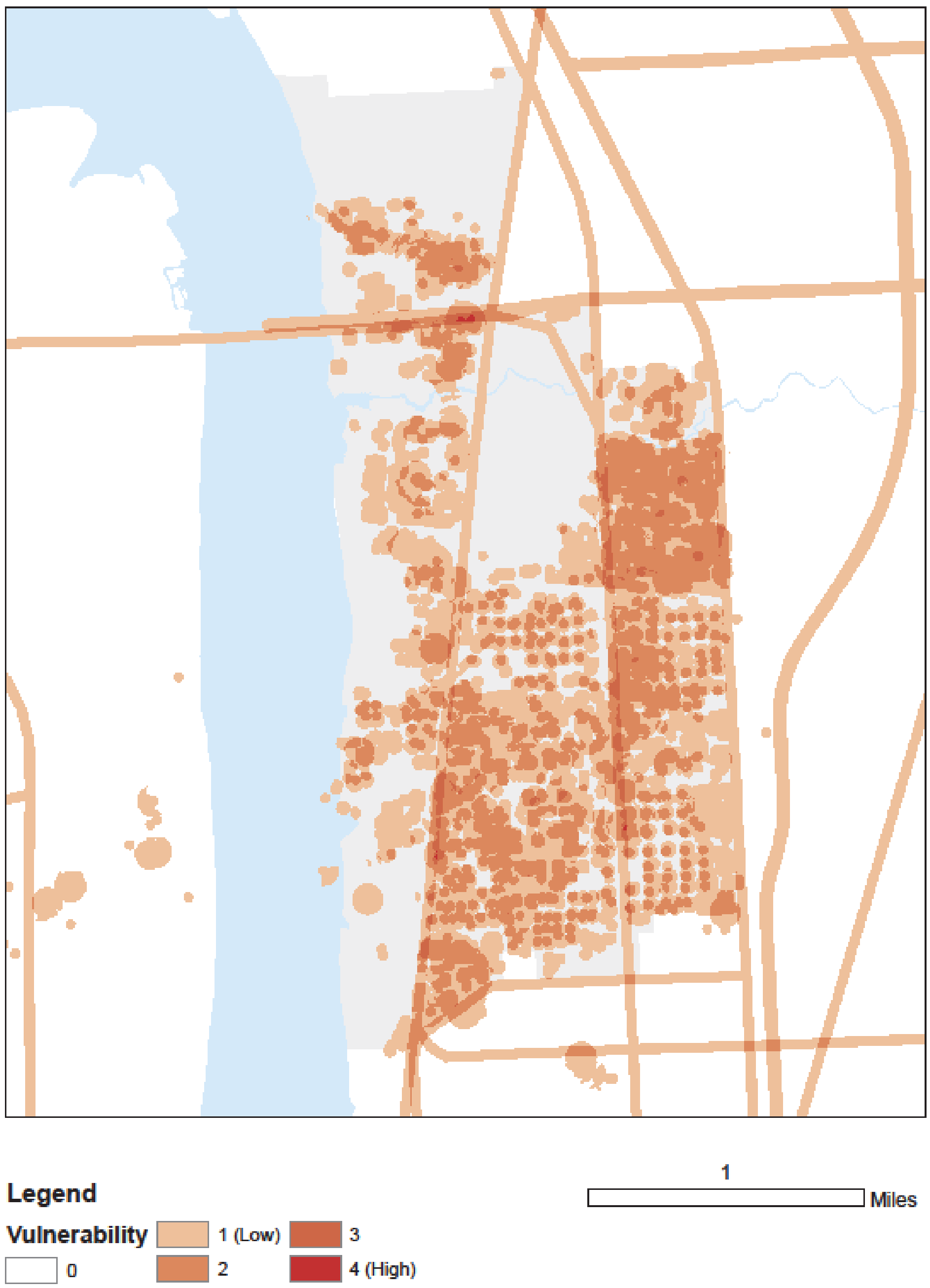


Figure 17. Contamination Overlay Map

2.3.4. Final Output

Figure 18. indicates final output within regional context. Subjective analysis was considered to use flood hazard area, soil data and existing habitat wisely.

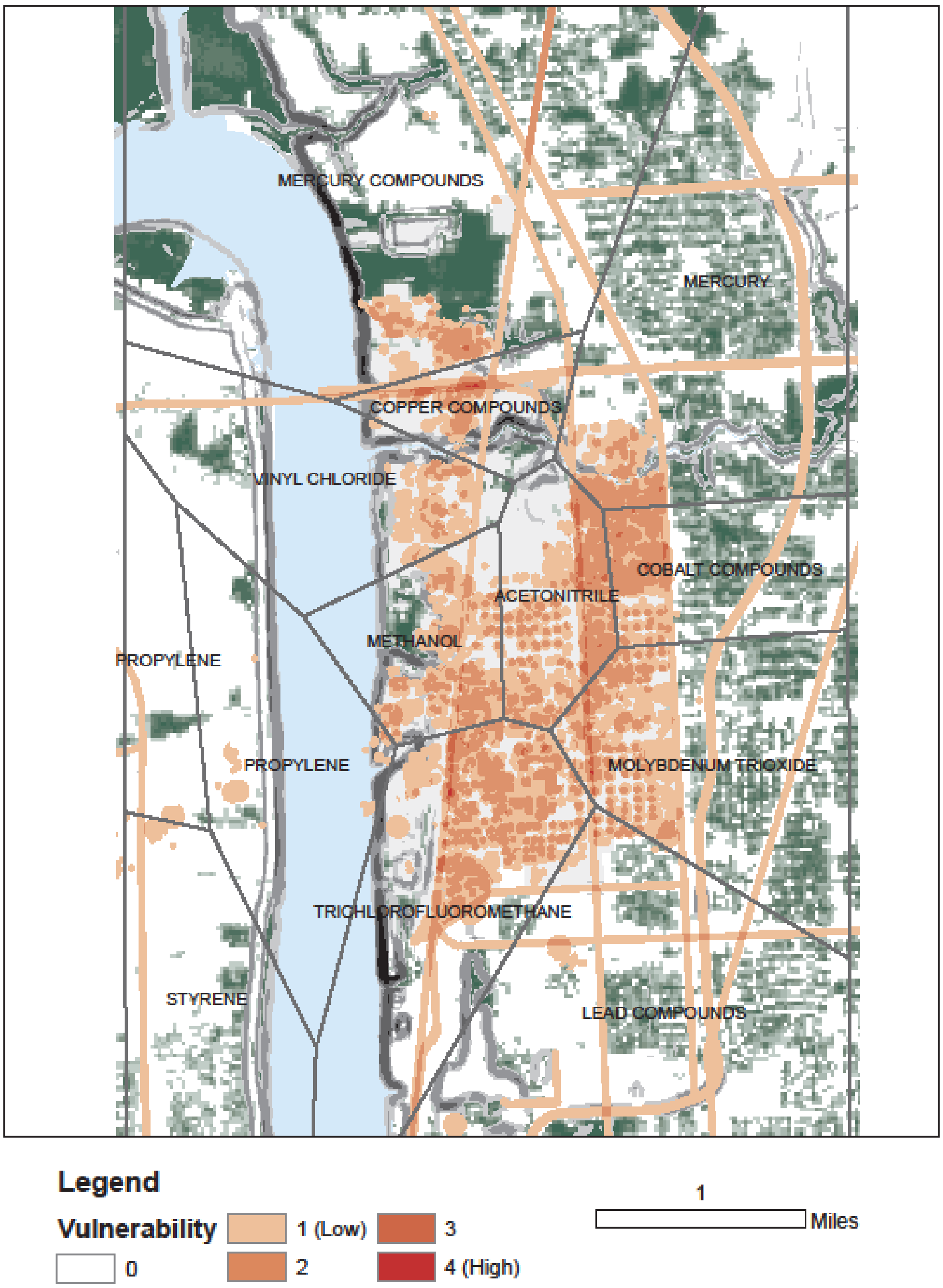


Figure 18. Final Output

2.2. Case studies

2.2.1. US Coast Guard Former Fuel Storage Facility

Location	Elizabeth City, NC
Date Installed [a]	2006 – 2007
Species Installed [a]	Hybrid poplar – Populus deltoids Bartram ex Marsh. X nigra L. Clones OP-367, DN-34, 15-29 and 49-177 Willow – Salix nigra “Marsh,” Salix interior “Rowle’s” and *Salix exigua* “Nutt.”
Contaminants [a]	TPH, BTEX, MTBE, PAH. Estimates from monitoring wells show 567,000 – 756,000 liters (150,000-200,000 US gallons) of gasoline, diesel, and aviation jet fuel at the site in the groundwater. Up to 85 centimeters (33 inches) of petroleum product was floating on top of the water table at the site.
Target Media [a]	Soil and groundwater with depth ranging from 0.9 to 1.2 meters (3-4 feet) below ground surface. The groundwater table fluctuates from 1.2 to 2.7 meters (4 to 9 feet) below surface except after major precipitation events.
Additional Lessons [a]	Tree height and growth rate as measured in 2010 correlated significantly with the TPH levels in the soil below. The lower the contamination, the higher the tree height, with more polluted areas having lower tree heights. The plants are acting as visual indicators of the contaminant concentrations below ground.
Timeline [a]	2006 – 112 bare-root poplars, 1.2 meters (4 feet) height, and 403 unrooted poplar and willow cuttings were installed. Plantings were placed in 8 centimeters (3 inches) diameter boreholes, 1.2 meters (4 feet) deep and backfilled with unamended on-site soil. Trees were mulched. All plantings were spaced 3 meters (10 feet) apart. Mortality averaged 28% because the contaminant concentration was too high for plant survival in some areas.

	2007 – 2176 new trees (2123 poplars, 43 willows, and ten trial Loblolly Pines) were planted in 23 centimeters (9 inches) diameter boreholes, 1.2 meters (4 feet) deep. Boreholes were backfilled with clean topsoil from off-site. Trees were mulched. All plantings were spaced 2 meters (6.5 feet) apart. Mortality decreased and averaged 13% because the borehole width was increased and boreholes were backfilled with clean soil to aid in plant establishment. 2007 – 65 poplars and 208 willows were planted using a dibble tool to create 15-30 centimeter (6-12 inch) deep holes wide enough for each cutting. No backfill was used. All plantings used a 2 meter (6.5 foot) spacing. Mortality averaged 89% because the soil was too contaminated for the establishment

[a] Nichols, Elizabeth Guthrie, et al. "Phytoremediation of a Petroleum-Hydrocarbon Contaminated Shallow Aquifer in Elizabeth City, North Carolina, USA." *Remediation Journal*, vol. 24, no. 2, 2014, pp. 29–46., doi:10.1002/rem.21382.

2.2.2. Biogeco Phytoremediation Platform (Bes and Mench, 2008; Bes et al., 2010; Bes et al., 2013; Kolbas et al., 2011; 2014; Marchand, 2011)

Location [a]	Gironde, France
Date Installed [a]	Risk assessment started in 2005; first field plots installed in 2006; research ongoing
Species Installed [b]	*Populus nigra L., Salix caprea L., Salix viminalis L., Agrostis Castellana Boiss. & Reuter, Agrostis delicatula Pour. Ex Lapeyr., Agrostis gigantea Roth., Dactylis glomerata L., Holcus lanatus L., Festuca pratensis* and *Cytisus striatus Hill Rothm*. Other perennials tested: for phytostabilization/ biomass production: Vetiver, Miscanthus, L. Annual crops tested for phytoextraction/biomass production: tobacco, sunflower, sorghum

Contaminants [a]	Heavy metals: copper (Cu) in the form of copper sulfate ($CuSO4$) and chromated copper arsenate used as a wood preservative; PAHs and hydrocarbons from creosote
Target Media [b]	Soil
Amendments [c]	1. Organic soil amendments 2. Soil Acidity/pH Soil Amendments 3. Mineral Soil Amendments and Conditioners 4. Microorganisms
Additional Lessons [b]	(1) Aggregation of knowledge from ecology, physiology, microbiology, molecular biology, analytical chemistry, and economy (life cycle risk assessment) allows to optimize, and up-scale phytoremediation options at the marketing level. (2) interactions between plants and microorganisms are a vast reservoir to improve phytotechnologies. (3) field trials are key-players for stakeholder acceptance

[a] Bes C, Mench M Remediation of copper-contaminated top soils from a wood treatment facility using in situ stabilization. Environment Pollution, 2008.
[b] Bes C, Mench M, Aulen M, Gaste H, Taberly J Spatial variation of plant communities and shoot Cu concentrations of plant species at a timber treatment site. Plant Soil, 2010.
[c] Marchand L, Mench M, Marchand C, Le Coustumer P, Kolbas A, Maalouf JP Phytotoxicity testing of lysimeter leachates from aided photostabilized Cu-contaminated soils using duckweed, 2011.

2.2.3. BASF Rensselaer Landfill

Location [a]	Rensselaer, NY
Date Installed [a]	2008
Species Installed [a]	Mixed forest ecotype planting including many New York native higher-evapotransportation rate species: *Alnus incana* (Grey Alder), *Acer rubrum* (Red Maple), *Aronia arbutifolia* (Red Chokeberry), *Betula nigra* (River Birch), *Castanaea dentate* (Chestnut), *Ceanothus americanus* (New Jersey Tea), *Cornus*

	amormum (Silky Dogwood), *Cornus racemose* (Grey Dogwood), *Cornus sericea* (Red Osier Dogwood), *Clethra alnifolia* (Sweet Pepperbush), *Fraxinus americana* (White ash), *Fraxinus Pennsylvania* (Green Ash), *Juniperus virginiana* (Eastern Red Cedar), *Poplus spp* (poplar hybrids), *Salix discolor* (Pussy Willow), *Salix Nigra* (Black Willow), *Sassafras albidum* (Sassafras), *Sambucus nigra* (Elderberry).
Contaminants [a]	VOCs (benzene, chlorobenzene, 1,2-dichlorobenzene, ethylbenzene, xylenes); heavy metals (arsenic, chromium, lead)
Target Media [a]	Soil and groundwater
Amendments [a]	0.7 meter (30 inches) soil cap over the existing landfill
Timeline [a]	~ 1978 - Wastes from a nearby chemical manufacturing plant were placed in the landfill when BASF purchased the site 1982 – Installation of a soil cap 1987 – Installation of a groundwater collection system 2008 – An alternative vegetated landfill cover was designed and installed to meet state landfill-closure regulations. A densely planted scheme with a thick soil cap was developed that would evapotranspire the majority of rain-water, thereby minimizing infiltration through the former landfill. The alternative landfill cover has been designed to include significant amenities, such as an environmental education center, walking trails, and an amphitheater. Moreover, the plantings were intended to maximize ecological value, providing wildlife habitat.

[a] "Phytotechnology Cover for Industrial Landfill Closure." Roux Associates, 2014.

2.3. Phytoremediation Database

1. Lead Compounds Cluster

Lead is one of the most common widespread contaminants in US urban areas, due to the historic use of leaded gasoline, lead paint, lead batteries, lead pipes and the continuing use of lead in industry. Lead in soils and in urban dust builds up cumulatively over time and is prevalent, and exposure to these sources in common. **Lead Poisoning** is the leading environmentally induced illness in children. **Children under the age of six are at greatest risk because of their fast neurological stage of development** and problems arising from lead ingestion, leading to the decline of mental development and acquisition of motor skills. (OSHA, 2013)

Botanical Name	Common Name	Size
Tree		
Acer rubrum	Red maple	69-90 feet tall and 2-3 feet in diameter
Aronia arbutifolia	Red chokeberry	3 to 8 ft
Betula Nigra	River birch	50-80' x 1-2' dbh
Fraxinus americana	white ash	medium to large tree; 100' x 24" dbh
Fraxinus pennsylvanica	green ash	medium-to-large tree, 100' x 24" dbh
Salix nigra	Black willow	large tree, 80-100 feet; fast growing
Sassafras albidum	Sassafras	medium sized tree, max 100' x 6' dbh
Sambucus nigra	Elderberry	shrub to 20 ft and 6" diameter
Juniperus virginiana	Eastern Red Cedar	may be pyramidal or columnar, may occur as shrubby horticultural forms; medium-sized tree, 40-50'
Shrubs - Large		
Helianthus annus	Sunflower	40" X 10 - 15' Spacing - 2' apart
Clethra alnifolia	Sweet Pepperbush	6-12 ft tall;

2. Metals: moderately dificult to extract - Cobalt (Co), Copper (Cu), Molybdenum (Mo)

Keywords: Phytoextraction

In soil: Stabilization - Plants are used to keep the contaminant on site preventing it from moving and creating

In water: To control contaminated groundwater: High evapotranspiration-rate species can be planted to control the groundwater plume, slowing it to prevent the spread of the contaminant in ground water. As the water in drawn into the plant, the metals are typically held in the root zone and soils around the plant. This hydrological control prevents migration of the metals in the groundwater.

To remove from surface and groundwater: The systems described below have been used widely for metals removal from water. Since constructed wetlands have been widely documented, plant species for these purposes have not been included in this publication. These metalks will not be readily available for plant-based extraction methods; however, the metals can be retained in a highly organic soil media.

Possible Design Options

1. Stormwater Filters	2. Multi Mechanism Buffers	3. Surface Flow Constructed Wetland

Design Considerations

1. Planted Stabilization Mat	2. Mass Water Balance	3. Variability and dormancy
5. Soil Chemistry	6. Amendments	7. Soil Buffer

Copper Case Study Plant Species		
Botanical Name	Common Name	Pollutants Dealing with
Poplus nigra	Black Poplar	Cu
Salix caprea	Willow	Cu
Sorghum halepense	Johnson grass	Cu

Figure 19. Phytoremediation Database (figure cont'd.)

Helianthus annuus	Common Sunflower	Cu
High Evapotranspiration-Rate Woody Plant Species		
Phytostabilization for Planted Stabilization Mat - Clean Soil buffer 4" - 6"		
Botanical Name	Common Name	Pollutants Dealing with
Tree		
Agrostis elliottiana	Bentgrass	As, Cu, Pb, Zn
Guardiola tulocarpus	Guardiola	Cu, Zn, Pb
Juniperus flaccid	Mexican Juniper	Cu, Zn, Pb
Populus alba	White Poplar	
Populus adeltoides	Eastern Cottonwood	
Betula nigra	River Birch	
Morus rubra	Red Mulberry	
Pinus taeda	Loblolly Pine	
Quercus virginiana	Live Oak	
Taxodium distichum	Southern Bald Sypress	
Black Willow	Salix nigra	
Species that seek out groundwater with long tap roots		
Botanical Name	Common Name	Size
Tree		
Acer negundo	Boxelder	mall-to-medium sized tree, <50' and 2' diameter
Acer rubrum	Red maple	69-90 feet tall and 2-3 feet in diameter
Cercidium floridum	Blue Palo Verde	
Fraxinus velutina	Velvet Ash	
Junglans microcarpa	Texas Walnut	
Platanus wrightii	Arizona Sycamore	
Prospis juliflora	Mesquite	
Prosopis velutina	Velvet Mesquite	
Prosopis stansburiana	Vanadium Bush	
Shrubs		
Alnus serrulata	Hazel aldar	1-3'
Baccharis emoryi	Emory Baccharis	
Baccharis glutinosa	Seepwillow	
Baccharis sarothroides	Desert Broom	
Baccharis sergiloides	Squaw Baccharis Waterweed	
Baccharis viminea	Mulefat	
Chilopsis linearis	Desert Willow	
Hymenoclea monogyra	Burrobush	
Larrea tridenata	Cresote Bush	
Sarcobatus vermiculatus	Greasewood	

(figure cont'd.)

3. Mercury Cluster - Difficult to Extract

Mercury may be able to be taken up and volatilized into the air by some genetically modified plants but mercury in air is also problematic.

Applicability: Extraction of these metals in soils by plants is not feasible. However, plants can contribute by stabilizing metals on site and by physically filtering particulates containing these metals from water. In addition, high-evapotranspiration plant species can stop them from migrating by controlling contaminant plumes in groundwater, as long as the concentration of the metal is not phytotoxic to the plants.

Planting specifics: The most effective phytotechnology application for soils with low-bioavailable metals is to bind the contaminants in place utilizing phytostabilization. Any plant species with dense root mats that prevent erosion can be used. Species that can withstand the strtess factors of these marginal sites should be considered.

In soil: Stabilization - Plants are used to keep the contaminant on site, preventing it from moving and mitigating an exposure risk. Amendments and pH level are typically adjusted to increase stabilization and enhance plant growth

In water: To control contaminated groundwater: High evapotranspiration-rate species can be planted to control the groundwater plume, slowing it to prevent the spread of the contaminant in ground water. As the water in drawn into the plant, the metals are typically held in the root zone and soils around the plant. This hydrological control prevents migration of the metals in the groundwater.

To remove from surface and groundwater: The systems described below have been used widely for metals removal from water. Since constructed wetlands have been widely documented, plant species for these purposes have not been included in this publication. These metals will not be readily available for plant-based extraction methods; however, the metals can be retained in a highly organic soil media.

Design Options

1. Stormwater Filters	2. Multi-Mechanism Buffers	3. Surface Flow Constructed wetland

Design Considerations

1. Planted Stabilization Mat	2. Mass Water Balance
3. Variability and dormancy	4. Maximize evaporation climatic factors

Species that seek out groundwater with long tap roots

Botanical Name	Common Name	Size
Tree		
Acer negundo	boxelder	mall-to-medium sized tree, <50’ and 2’ diameter
Acer rubrum	Red maple	69-90 feet tall and 2-3 feet in diameter
Cercidium floridum	Blue Palo Verde	
Fraxinus velutina	Velvet Ash	
Juglans microcarpa	Texas Walnut	
Platanus wrightii	Arizona Sycamore	
Prosopis juliflora and Prosopis pubescens	Mesquite	
Prosopis velutina	Velvet Mesquite	
Prosopis stansburiana	Vanadium Bush	
Shrubs		
Alnus serrulata	hazel alder	Shrub or small tree
Baccharus emoryi	Emory Baccharis	Shrub
Baccharis glutinosa	Seepwillow	Shrub
Baccharis sarothroides	Desert Broom	Shrub
Baccharis sergiloides	Squaw Baccharis Waterweed	Shrub
Baccharis viminea	Mulefat	Shrub
Chilopsis linearis	Desert Willow	Shrub

(figure cont'd.)

Hymenoclea monogyra	Burrobush	Shrub
Larrea tridentata	Cresote Bush	
Sarcobatus vermiculatus	Greasewood	
High Evapotranspiration-Rate Woody Plant Species		
Tree		
Populus alba	White Poplar	
Populus deltoides	Eastern Cottonwood	
Betula nigra	River Birch	
Morus rubra	Red Mulberry	
Pinus taeda	Loblolly Pine	
Quercus virginiana	Live oak	
Taxodium distichum	Southern Bald Sypress	
Black Willow	Salix nigra	

4. Chlorinated Solvents - Vinyl Chloride Cluster

Design Elements: Groundwater typologies for chlorinated solvents

* Hydraulic control time frame: 2- 10 years or more (highly dependent on how contaminated the groundwater is, speed and volume of plume, climate and evapotranspiration rate of chosen species.)

1. Interception Hedgegrow - Deep Rooted - No Harvest Necessary

Mechanisms: Rhizodegradation, Phytodegradation, Phytovolatilization, Phytohydraulics, Phytometabolism

Target: Groundwater

Species that seek out groundwater with long tap roots

Botanical Name	Common Name	Size
Tree		
Acer negundo	Boxelder	Small to medium sized tree, < 50' and 2' diameter
Acer rubrum	Red maple	60-90 ft tall and 2-3 ft in diameter
Cercidium floridum	Blue Paldo Verde	
Fraxinus velutina	Velvet Ash	
Juglans microcarpa	Texas Walnut	
Platanus wrightii	Arizona Sycamore	
Prosopis Juliflora	Mesquite	
Propois velutina	Velvet Mesquite	
Prosopis stansburiana	Vanadium Bush	
Shrubs		
Alnus serrulata	Hazel alder	
Baccharis emoryi	Emory Baccharis	
Baccharis glutinosa	Seepwillow	
Baccharis sarothroides	Desert Broom	
Baccharis sergiloides	Squaw Baccharis Waterweed	
Baccharis viminea	Mulefat	

(figure cont'd.)

Chilopsis linearis	Desert Willow	
Hymenoclea monogyra	Burrobush	
Larrea tridentata	Cresote Bush	
Sarcobatus vermiculatus	Greasewood	

2. Groundwater Mitigation Tree Stand - Fast Transpiring plant		
Plant species		
1. Hybrid Poplars	2. Willows	
** Other Design Considerations*		
1. Mass Water Balance	2. Variability and dormancy	3. Maximize evaporation climatic factors - Greater Solar Exposure, Higher Temperature, Increased aircirculation

3. Phytoirrigation		
Plant species		
1. Sunflower	2. Populus	3. Salix

Mechanisms: Rhizodegradation, Photodegradation, Phytovolatization
Target: Wastewater or groundwater
Contaminants addressed: Nitrogen, Chlorinated Solvents, Petroleum, Selenium

4. Soil Degradation - Degradation time frame: 1-10 year or more

4. 1. Degradation Cover - No Harvesting Necessary
Mechanisms: Rhizodegradation, Phytodegradation, Phytovolatilization, Phytometabolism
Target: Surface Soils (0 - 1.5meters / 0 - 5 ft deep)
Contaminants: Petroleum, Chlorinated Solvents, Nitrogen

4.2. Degradation Hedge
Target: Surface Soils

1. Layering	2. Pruning and maintenance pruned per a year	3. Irrigation of Living Fences Willow species need water to grow

4.3. Degradation Living Fence

4. 4. Degradation Bosque
** Phytotoxicity - Any new oxygen and biological activity that are introduced into the soil via the roots of the plants will be a benefit to the contaminant breakdown*

5. Petroleum

Same Planting Lists as 4, but more options
Design Options

1. Green Infrastructures	2. Stormwater Filters	3. Surface-Flow Constructed Wetland

Botanical Name	Common Name	Size
Tree		
Andropogon gerardii	Big Bluestem	
Bouteloua curtipendula	Side-Oats Grama	
Celtis laevigata	Sugar-Berry	
Cercis canadensis	Redbud	
Elymus canadensis	Canada Wild Rye	
Elymus hystrix	Bottle-Brush-Grass	
Fraxinus pennsylvanica	Green Ash	

2.4. Scenario Analysis

Figure 20. demonstrates that there are four different contaminated level in the study area.

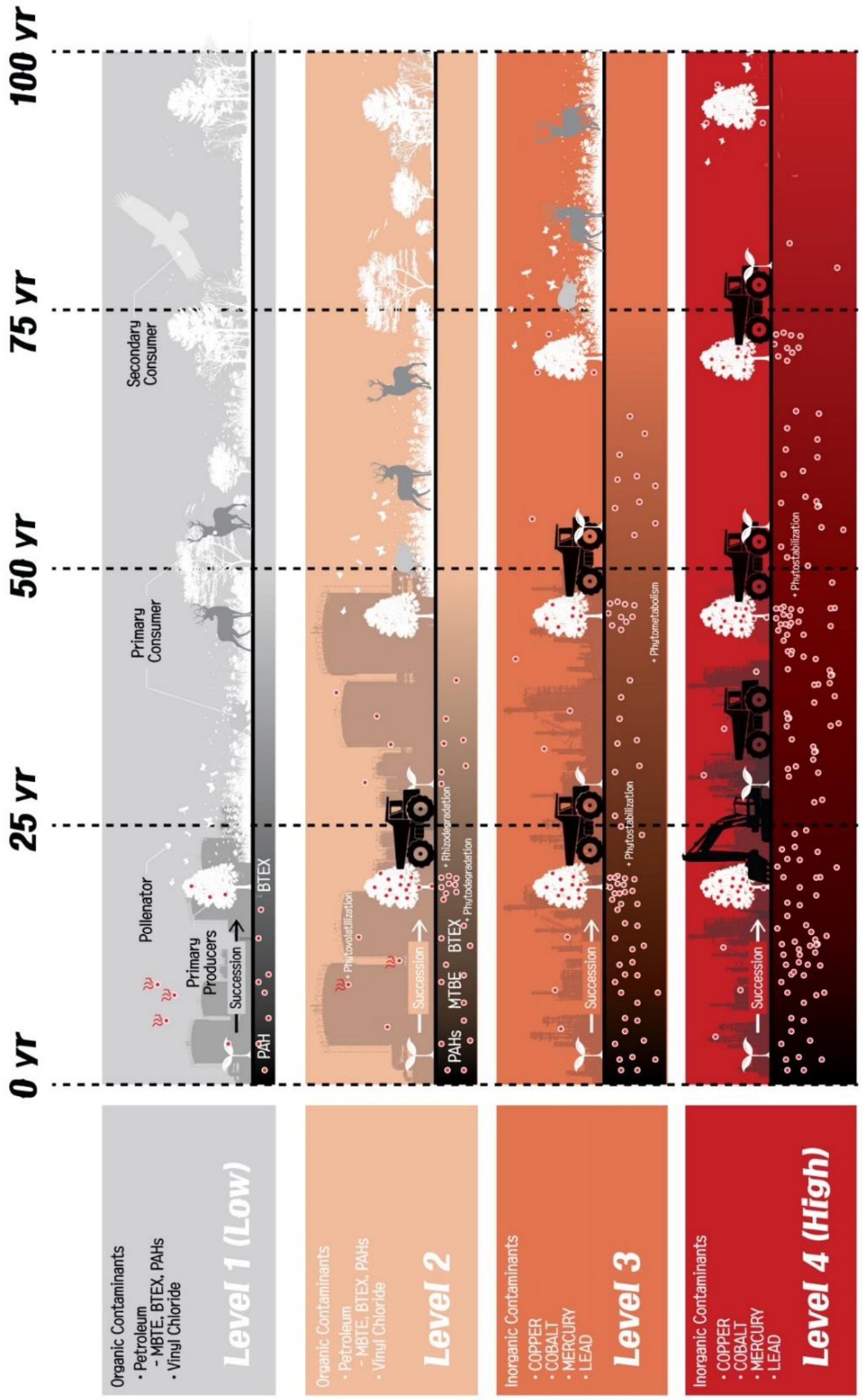


Figure 20**.** Scenario Analysis

Level I is relatively less contaminated so that it is faster to increment healthier landscape by bringing back from pollinators such as primary producer, primary consumer to secondary consumer. Level II takes larger time to cleanse because of the complexity of contamination. Level II was shown either between rail corridor and small equipment within 50ft, or either between sparse equipment. Therefore, it is evident that the contamination is more complexed than the Level I.

Contaminants can be categorized into two; organic pollutants and inorganic contaminants. The most significant difference between two is whether it can be extracted or not. Different landscape typologies should be installed on various pollutants. For example, copper and lead compounds are difficult to evapotranspire through vegetation, and therefore it is better to stabilize those metal in soil and harvest trees later on. Once the plant used for phytostabilization get harvested, new saplings will alternate those barren areas. Then, the similar incremental process like Level I will happen repeatedly. For the mercury compound area, created by Voronoi diagram using EPA Toxic Release Inventory data in 2013, it would be better to restrict all the access tentatively since it’s almost impossible to take out. There must be new technology coming up to cleanse mercury or new policy coming up to allocate enough budget to excavate a mass of highly contaminated soil. This area will be dealt then.

CHAPTER 3. RESULTS

3.1. Design Check Lists

Figure 21. and Figure 22. summarizes design check lists of each contaminants compound area.

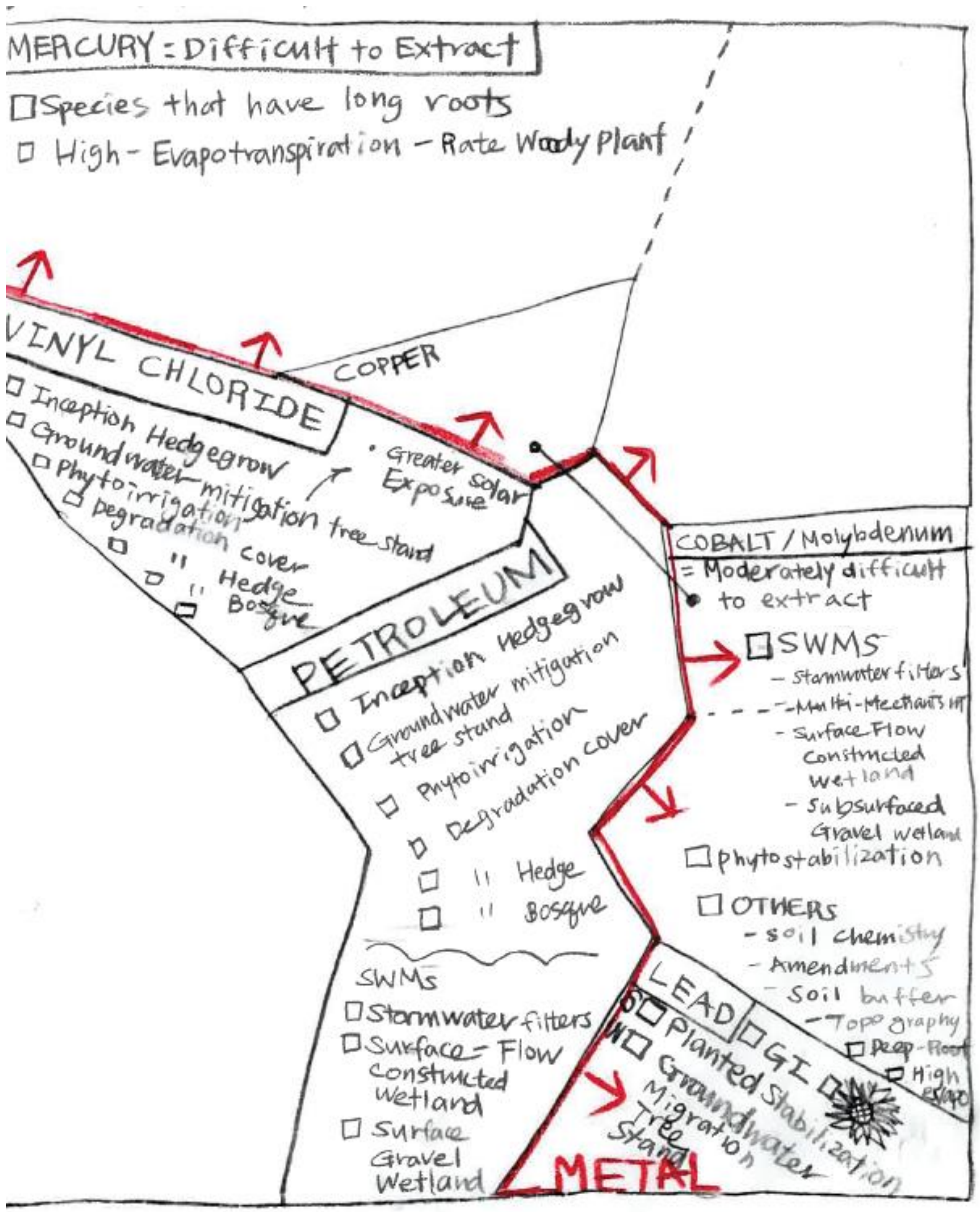


Figure 21. Design Check Lists based on TRI Voronoi Diagram

1. Lead
    1) Planted Stabilization
    2) Groundwater Migration Tree Stand

2. Copper / Cobalt
    - Stormwater Management
    - Stormwater Filters
    - Multi-mechanism Mat
    - Surface Flow Constructed Wetland
    - Subsurface Gravel Wetland
  1) Phytostabilization
  2) Others
    - Soil Chemistry
    - Amendments
    - Soil Buffer
    - Topography
    - Deep-Root

2. Mercury
  1) Species that have long roots
  2) High-Evapotranspiration Rate Woody Plant

3. Vinyl Chloride
  1) Inception Hedge Grow
  2) Groundwater Mitigation Tree Stand
  3) Phytoirrication
  4) Degradation Cover
  5) Degradation Hedge
  6) Degradation Bosque

4. Petroleum
  1) Inception Hedge Grow
  2) Groundwater Mitigation Tree Stand
  3) Phytoirrication
  4) Degradation Cover
  5) Degradation Hedge
  6) Degradation Bosque
  7) Stormwater Management
    - Stormwater Filters
    - Surface-Flow Constructed Wetland
    - Surface Gravel wetland

Figure 22. Design Check Lists for Each Petrochemical Pollutants

3.2. Former Manufactured-Gas Plants: Design Ideas

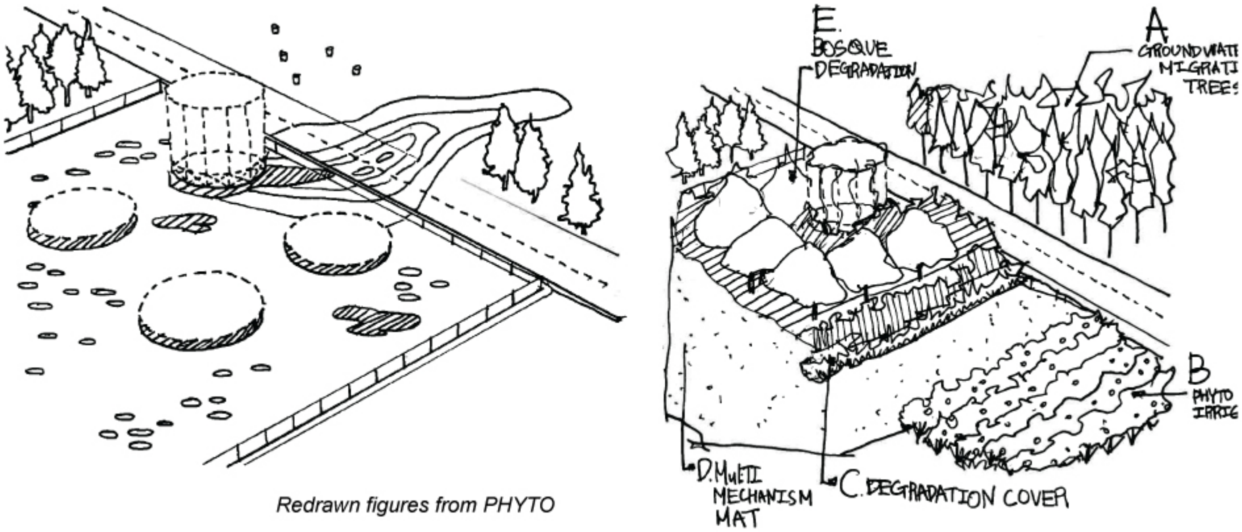


Figure 23. Former Manufactured-Gas Plants: Design Ideas

According to the Phyto (Kate and Niall, 2015), There are three primary sources in the manufactured-gas plants (Figure 23.); Urban fill, Leachate, and Gas tank foundations. MPGs were often constructed at river edges where sites were filled with debris to create usable land. Leachate around MGP sites can be cleansed and irrigated onto plantings to potentially remove the pollutants from the leachate and prevent the plume from migrating by the phytoirrigation mechanism. Trees can be installed to tap into polluted groundwater and plumes, absorb the water and degrade the petroleum. Within old MGP foundations where coal tar is likely, Degradation Bosques can be installed to break up the petroleum and degrade it over time. Under bosques of trees, shorter plants can be used to create a degradation cover to remediate oil found in surface soils. Also, Multi-Mechanism Mats can be designed to stabilize non-extractable metals, while slowly degrading tough PAH petroleum.

3.3. Gas Tank – Design Ideas

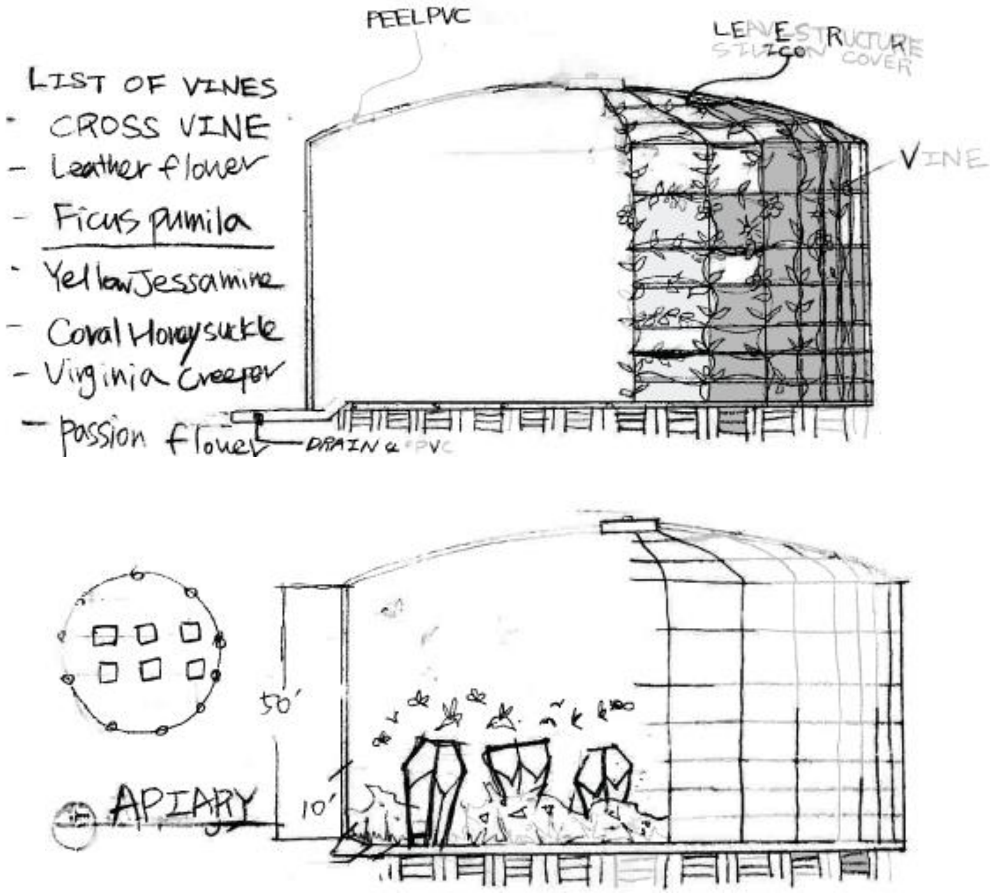


Figure 24. Gas Tank – Design Ideas

Like Gas Works Park in Seattle, the site would contain remnants of the sole remaining petroleum plant. The soil, tank infrastructure and groundwater of the site has been highly contaminated for almost a hundred years. The idea (Figure 24) will be a unique landmark for the North Baton Rouge. The original structures will function as idustrial archaeology and the remaining examples of the Industrial revolution. Take out crust of the structure and just remain linear pipes of the structure. With many different kinds of native vines in Louisiana, which also function as phytoremediation will show dynamic incremental landscape of the future park. Apiaries within the green structures would even facilitate the richness of landscape. There would be irrigation system within the clean new infrastructure, which would represent the old structures.

3.3 Master Plan

Figure 25. included most of design check lists to maximize the rate of phytoremediation. Master plan for a hundred year later is as follows.

Figure 25. 100-Year Later Master Plan

CHAPTER 4. DISCUSSION

This research demonstrated phytoremediation principles in Baton Rouge Cancer Alley by using subjective and objective analysis. The main findings and implications of the study are as follows.

First, the essential attributes identified objective, weighted overlay analysis. The vulnerability map of the study area was defined according to this method to categorize the level of contamination across the site. Data for the analysis were collected from the U.S. Department of Transportation and Louisiana Department of Environmental Quality. The study results imply that the primary reason for the high level of the contamination zone tends to locate between industrial clusters and the railway because these sites have highly mixed contaminants. With respect to another objective analysis, the Voronoi diagram was created by geo-processing of the Toxic Release Inventory point data produced by the U.S. Environmental Protection Agency in 2013. This diagram showed assumed range and the mass of specific contaminants. On the basis of the objective analysis, different phytoremediation design typologies applied to each level of contamination in the Master Plan.

Second, the National Flood Hazard Layer created by FEMA was considered an essential factor for design as well. The high risk of flood hazard area is often regarded as the area to avoid design. However, the subjective analysis was used to interpret this data, because, in this particular brownfield, this area has high potential to be an excellent phytoremediation opportunity since high evapotranspiration species can remediate specific contamination faster. Species that have higher evapotranspiration rates move more water from the soil to the atmosphere and therefore can better capture contaminants in water than can other species. This is especially important when the contaminant is mobilized in water, such as in stormwater or groundwater (Kate and Niall, 2017). Based on the slope map, deep-root planting techniques or ‘Room for the River’ strategies were applied to the 8.3% of areas. Also, the layered tree canopy map and the wetland map indicated that species could be harmonious with the existing habitat to create a buffer zone adjacent to the study area.

The results of the study helped site design as well as phytoremediation strategies in 100-year phases. Regarding the sustainability map created by the vulnerability map with the subjective interpretation mentioned above, particular design typologies were designated across the site. In particular, the organic and inorganic contaminants zone showed a different phytoremediation temporal framework. This is attributed to the fact that organic contaminants within the desired log K_{ow} (octanol-water partition coefficient) range between 0.5 and 3.5 can be extracted relatively easier than inorganic pollutants using various phytoremediation mechanisms such as phytodegradation and rhizodegradation without harvesting process. However, inorganic contaminants cannot be degraded at all in the plant or root zone. The target mechanism is either extracted into the plant, stored and harvested using hyperaccumulating species or high biomass species (Kate and Niall, 2017) in which may be hard to create a rich habitat. Therefore, as time goes by, an incremental landscape is shown in the organic contaminants zone, reintroducing other butterflies and insects, while the inorganic contaminants zone is kept harvesting. In response to climate change, the design also considered Louisiana's environmental attributes such as rising sea levels, potential land loss, and temperature. This study is the first research to propose phytoremediation design strategies at an oil refinery in Baton Rouge. The results of the study can help planners understand the contamination as well as their perception of phytoremediation based on different conditions. One of the limitations of the study concerns the generalization of the results due to the lack of field survey. It was hard to get specific contamination data for a facility within the study area since a private company owns the research area. As such, further studies are needed to compare levels of contamination using the data from the field survey to investigate more specific contamination zones and types. Given the lack of research regarding phytoremediation planning strategies, particularly in Louisiana Cancer Alley, this study could help planners understand the clean-up process using plants within an industrial area and provide insights into future brownfield management.

CHAPTER 5. CONCLUSION

The study found that there are different levels of contamination in the study area based on facilities, transportation, and other infrastructures. It was concluded that the design typologies for different contamination zones might help facilitate the cleansing process for brownfields. Brownfields need to continue their role in transforming contaminated land, providing a more sustainable place for remediation and awareness of stewardship. Because phytoremediation can be as little as 3% of the cost of traditional cleanup costs, more and more developers and planners prefer a cost-effective solution like phytoremediation. These design methods and principles can be applied to the other industrial areas within Louisiana Cancer Alley as well, which has similar environmental conditions. However, it is always encouraged that landscape architects work closely with a team of experienced phytotechnology scientists because there are many applications where it is difficult due to the different environmental factor. The recent increase of public interest in Cancer Alley and the purpose of brownfields as educational and ecological places are expected to encourage more studies on the demands of residents' health and their satisfaction with the healthy environment.

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VITA

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