

Alternative Future of Revitalizing Decommissioned Coal-Fired Power Plant Sites:

An Alternative Scenario Approach in Trenton, Michigan

Diva Alfirman, Ye Jia, Lauren Mleczko, Changtong Wu, Sumire Yamada, and Yuxiao Yue

School for Environment and Sustainability, University of Michigan

Advisor: Joan Iverson Nassauer

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Acronyms Used

1. 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)
2. Biological sulfate reduction (BSR)
3. Carbon dioxide (CO₂)
4. Concentrated solar power (CSP)
5. Contaminants of emerging concern (CECs)
6. Cost-Surface Modelling (CSM)
7. Dichlorodiphenyltrichloroethane (DDTs)
8. Electrokinetic remediation (EKR)
9. Environmental Protection Agency (EPA)
10. Ethylenediaminetetraacetic acid (EDTA)
11. Genetically modified microorganisms (GEMs)
12. Light emitting diode (LED)
13. Metallothionein (MT)
14. Methane (CH₄)
15. Michigan Department of Environment, Great Lakes, and Energy (EGLE)
16. Mineral-associated organic matter (MAOM)
17. Multi-criteria involvement process (MIP)
18. Permeable reactive barriers (PRBs)
19. Per- and polyfluoroalkyl substances (PFAS)
20. Photovoltaic cells (PV cell)
21. Polychlorinated Biphenyls (PCBs)
22. Polycyclic aromatic hydrocarbons (PAHs)
23. Sahiwal Coal Fired Power Plant (SCFPP)
24. Soil organic carbon (SOC)
25. Species-Area Relationship (SAR)
26. Superfund Research Program (SRP)
27. Trenton Channel Power Plant (TCPP)
28. Zero-valent iron (ZVI)

Land revitalization is considered a beneficial, yet costly, process. The importance of land revitalization is underpinned by the fact that past land uses may contaminate land, with remediation being required for future land uses (U.S. Environmental Protection Agency, 2023). In some cases, sites that contain pollutants and contaminants pose a direct threat to human health, so treatment of contaminated sites is important (Haninger et al., 2017).

Brownfield sites are a widespread example of land contamination. The U.S. Environmental Protection Agency (EPA) defines a brownfield as “a property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.” (Haninger et al., 2017). In the U.S., many hazardous sites are no longer operational but remain unremediated (Alberini et al., 2005). The environmental risks posed by these sites vary with relatively few highly contaminated areas and a large and diverse set of small scale, lower risk sites (Eckerd & Keeler, 2012). Nevertheless, widespread pollution from previous industrial activities has driven detrimental human health effects, especially in urban areas. Remediation and redevelopment are needed to support the sustainable transition of brownfield sites and increase urban ecosystem services (Hou et al., 2023).

This project presents a possible future scenario for a site with a likely contaminant history: the former Trenton Channel Power Plant (TCPP) located in Trenton, Michigan. Trenton is within Wayne County and is located downriver from Detroit (Figure 1).

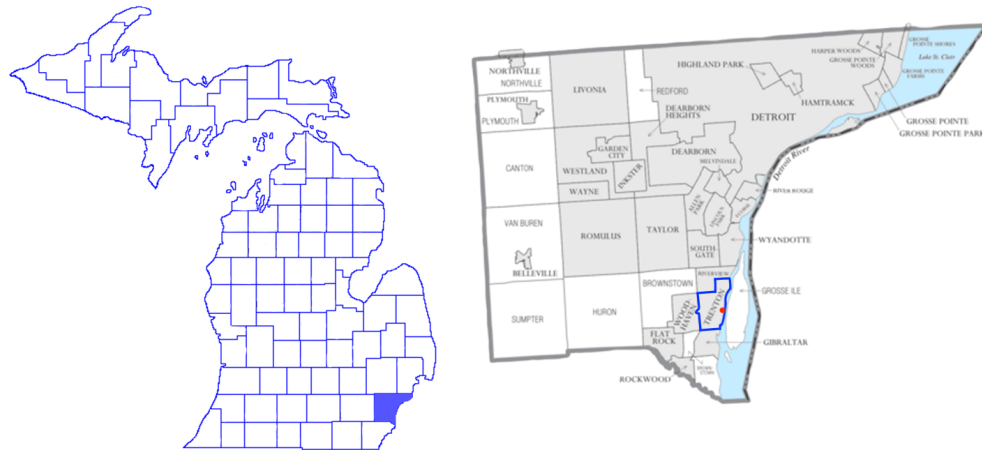


Figure 1: Wayne County is highlighted in blue in the left map, and the cities within Wayne County are in greater detail on the right. Trenton is in the southern portion, indicated with a blue outline, and the approximate location of the former TCPP is indicated with a red circle. (*Wayne County, MI census map 2, 2019; Michigan Counties Map, 2025*).

The redevelopment of the 191-acre TCPP site could transform it into a vibrant hub for ecological restoration and community activities. In this project, an alternative scenario is compared to a control scenario, with consideration for five variables: carbon sequestration, energy generation and storage, habitat quality and connectivity, human use, and potential remediation techniques. The alternative design ultimately emphasized habitat quality and connectivity, with consideration given to the remaining four variables. The control and the alternative scenarios were assessed against these variables to explore potential future uses and the possibilities that exist for them. To successfully do so, the project team:

1. Completed a literature review of community engagement, remediation strategies and contamination patterns at similar sites, best practices, and the different assessment variables;
2. Defined and created assessment matrices for different assessment variables;
3. Analyzed options for a possible site design to maximize ecological benefit, through habitat restoration and improvement, and minimize risk to the public;

4. Created an alternative design scenario that emphasizes habitat quality and connectivity;
and
5. Evaluated the control and alternative scenarios against the matrices for each variable.

This paper will introduce the designs for the control scenario and the alternative scenario, expanding upon which aspects of the variables are present in each. It will then outline some of the relevant context of the project site, offer an analysis of the site, and move into a literature review of the variables under consideration and how they will be assessed. The site context, site analysis, variable literature review, and variable assessment matrices will inform the design process for the alternative design, which is explained further in these sections. Next, the evaluation of the control and alternative scenario against the variables is discussed. To conclude, commentary is offered on the potential design future put forward in this paper for the project site and what these results could indicate in other contexts.

Context of the Project Site

Geographical Context

The project site (Figure 2) sits just to the south of Elizabeth Park, a public park owned by Wayne County. To the south of the site is a Solutia chemical plant and the Detroit River International Wildlife Refuge, which is composed of over 30 parcels, including land that sits on a former industrial site and Humbug Marsh, a community-initiated effort that saved a bog from development (*Detroit River International Wildlife Refuge | About Us*, n.d.). A bike and pedestrian route that spans Michigan, the Iron Belle, abuts each of these properties along Jefferson Road to the east. This is a possible connection for future uses of the project site, and includes the North-South trail that is part of the Downriver Linked Greenways Initiative, a nonprofit organization that aims to facilitate trail creation downriver of Detroit (*North South*

Trail, n.d.). The route of the North-South trail (Figure 2) is part of the larger Iron Belle trail that spans Michigan.

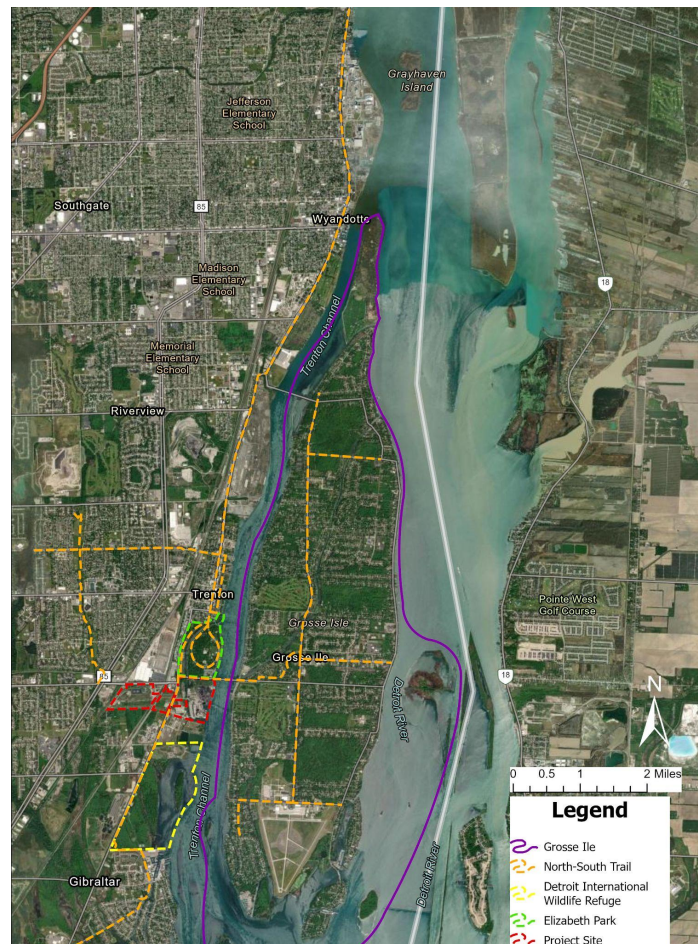


Figure 2: The project site (bordered with a red dashed line) and surrounding areas of Grosse Ile (bordered with a purple dashed line) Elizabeth Park (bordered with a green dashed line), and the Humbug Marsh and visitor center parcels of the Detroit International Wildlife Refuge (bordered with a yellow dashed line). The route of the North-South trail is indicated in orange, which is part of the larger Iron Belle trail (*North South Trail*, n.d.).

History of Operation

The TCPP began operation in 1924 and was retired in 2022 (Clarke, 2024). When in operation, it was a coal-fired power plant owned by DTE Energy, a Michigan-based electric and gas utility company. In 1950 a second coal-fired plant began operation at the site, and by the

mid-1970s, the original 1924 plant was put out of service (Clarke, 2024). The 1950 addition, alongside additional modifications, continued operation until 2022 and was demolished in spring 2024 (Clarke, 2024). Having been in operation for almost 100 years, it had become an iconic part of the city of Trenton, likely in part due to the imagery of the two smokestacks present at the plant (Figure 3).



Figure 3: The TCPP when it was in operation (Fischer, 2024).

Historical Context

Understanding the historical context of brownfield sites is paramount in remediating a site, emphasizing the need for transparency within its community (Erdem & Nassauer, 2013). Michigan's Native American history is deeply rooted in the cultural and political lives of tribes such as the Anishinaabe, comprising the Ojibwe (Chippewa), Ottawa (Odawa), and Potawatomi tribes, which are part of the Council of Three Fires, an alliance that held a strong presence in the Great Lakes region, especially around Michigan.

However, the tribe that lived closest to the project site under consideration here, the Wyandotte, were not Anishinaabe. The Wandat, known today as Wyandotte, began to live near

Fort Detroit in 1701 (Wyandotte Nation, 2022). They formed from “the remnants of the Tionontati, Attignawantan and Wenrohranon (Wenro), all unique independent tribes, who united in 1649-50 after being defeated by the Iroquois Confederacy” (Wyandotte Nation, 2022). They did not have any known villages in present-day Trenton, but there was one located to the south of Trenton and one located to the north, as shown in Figure 4 (Hinsdale et al., 1931).

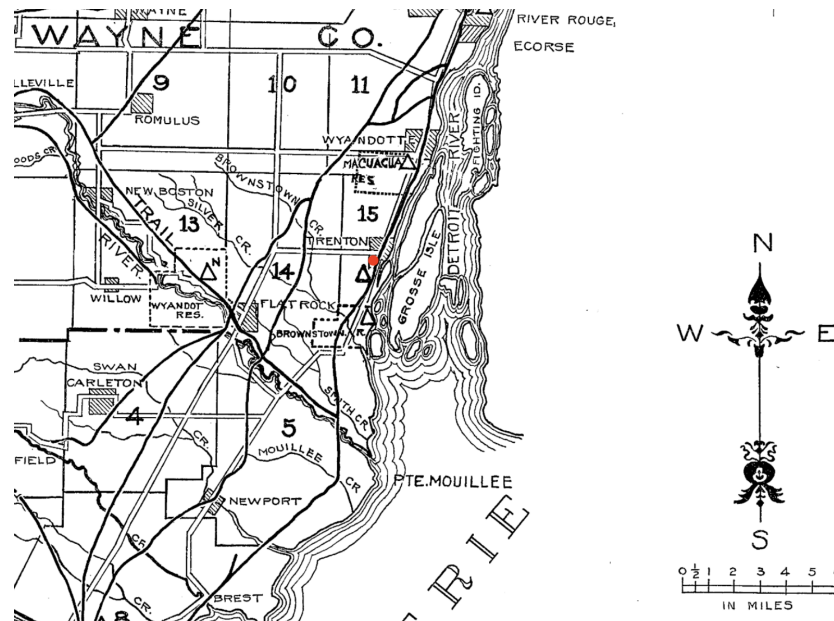


Figure 4: Excerpt from Hinsdale et al. (1931), showing Trenton along the Detroit River and Grosse Ile across from it. The triangles indicate Native American villages, and the red dot indicates the approximate location of the project site.

After the American Revolution and departure of the British, the U.S. claimed Michigan as part of its Northwestern territory. The Treaty of Detroit (1807) and other agreements led to the loss of large territories for Native Americans in southeastern Michigan, including the Detroit area. This led to the displacement or fracture of many indigenous communities (Cleland, 1992). In 1815, the Wyandot were removed from the Detroit River area and placed in a reservation in Flat Rock, Michigan along the Huron River (Wyandotte Nation, 2022). However, some were able to remain in Michigan while others were forcefully removed, and the Wyandot of Anderdon Nation are still in the area today (Wyandotte Nation, 2022). The name Wyandotte was adopted

by approximately 200 individuals who were reinstated as a tribe with the 1867 Treaty (Wyandotte Nation, 2022) The Detroit River area, while transformed over time, still holds historical significance for Native communities and continues to be a place where tribes advocate for environmental stewardship and historical acknowledgment.

Focusing specifically on the project site, the city of Trenton has a history back to 1850 when it was first laid out by settlers Truax, Slocum, Bird, Atwood, Edward, Wagstaff, and Davis. The Slocum family, in particular, was one of the primary landowners of the area, and owned the land Slocum Junction was on, giving it its name (Figures 5 & 6).

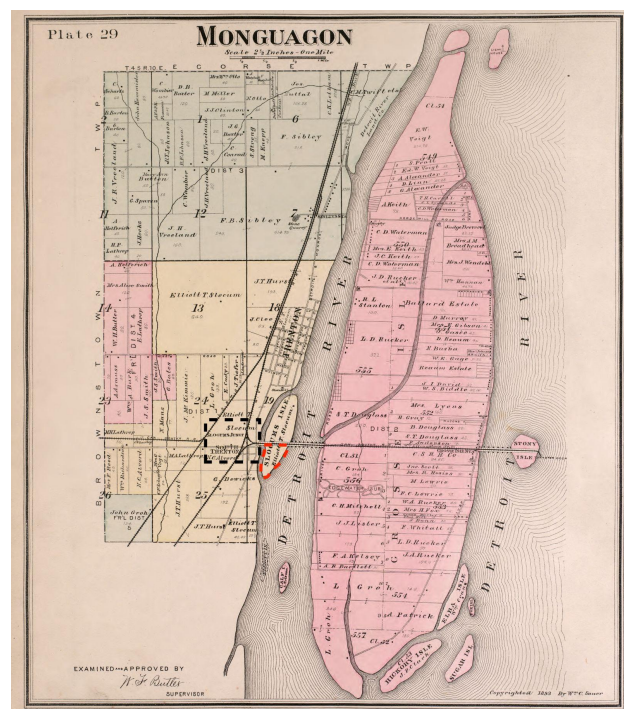


Figure 5: Excerpt from Sauer (1893), showing Monguagon township, which includes the project site (approximately indicated with a red dashed line) and Slocum’s Junction (boxed with a black dashed line). Slocum’s Junction is shown in greater detail in Figure 6. Grosse Ile is shown in pink to the right of the project site.

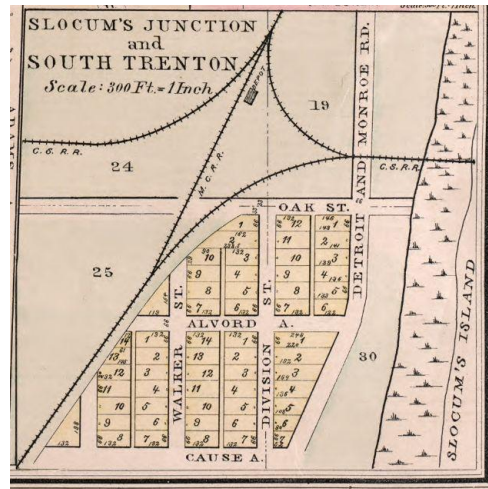


Figure 6: Excerpt from Sauer (1893) showing Slocum's Junction in greater detail and south Trenton. The project site is not visible on this map, but it is slightly southeast of what is shown here.

Slocum's Junction was, at the time, the grade crossing of the Canada Southern railroad, which ran from Ontario, Canada to Fayette, Ohio via Flat Rock, and the north and south Michigan Central line, which ran from Detroit to Toledo. The Detroit & Toledo Shore Line was built parallel to the Michigan Central line and crossed the Canada Southern line here as well (Administrator, 2024). The Canada Southern was purchased by Vanderbilt interests and truncated just east of the crossing, and the crossing did not exist long after this purchase. However, the location survived in a different way as north and south Y-shaped (or "wye") tracks were connected to the Michigan Central main line. After rail service was discontinued to Grosse Isle, which is across the Trenton Channel from Trenton, the south wye/interlocker remained so that the Michigan Central could serve industrial trackage along the Detroit River.

In the 1950s, the Downriver area was heavily industrialized, with manufacturing, steel production, and automotive industries dominating the economy. This region was critical to Michigan's (and to an extent, America's) economic engines, largely due to its proximity to the Detroit River, which was instrumental in facilitating trade and transport activities for companies such as The Ford Motor Company, Great Lakes Steel, and McLouth Steel, all which established

plants in the region, helping boost population growth and create job opportunities (The Down River Chamber of Commerce, 1953). Unfortunately, the rise in industries along the Detroit River led to increased pollution, affecting the water quality and health of local ecosystems. Decades of discharges, waste dumping, and emissions contributed to environmental degradation, which required ongoing remediation efforts to restore water and soil quality. Many former industrial areas consequently were contaminated. This has led to modern-day initiatives focusing on remediation and adaptive reuse for safer community spaces and sustainable development when considering future land uses.

Possible Stakeholder Groups

The project site is just south of Elizabeth Park, just north of the Detroit River International Wildlife Refuge, and nearby the Downriver Linked Greenways Initiative's North-South Trail (Figure 2). As previously discussed, connection to these sites is likely desired. This site is located in an area where nearby parks do not have tennis courts, pickleball courts, or water parks and/or splash pads, and so providing these options could fill a gap for community members (Southeast Michigan Council of Governments, 2015). When combined with proper access points, this could provide a meeting space between the likely users of this site, residents of Trenton and Grosse Ile, and the larger regional community, which could include residents of surrounding towns or, more broadly, Wayne County residents (Figure 1).

What sort of space would be best, however, is uncertain without proper community engagement strategies. As the project logistics did not allow the team to do community engagement activities, a hypothetical approach of considering the possible stakeholders in the area that would have an interest in the future of the project site was used. To begin, DTE would be an important stakeholder to consider, as they have a long history at this site and in the region.

As a battery storage facility has already been announced for part of the project site, DTE will have an interest in what future use the rest of the site holds (Owings, 2024).

One main group of stakeholders would be those located near the project site. This could include the municipal governments and residents of Trenton and neighboring cities, like Grosse Ile, Riverview, Woodhaven, Gibraltar, or larger Wayne County (Figure 1). Whether neighboring cities would want to be involved would likely be up to the level of interest of their residents and budgetary constraints at the governmental level, but a regional lens would indicate that more than just the Trenton government might have an interest in the site.

Further, since Elizabeth Park is a county park, controlled by Wayne County Parks & Recreation, they would potentially also have an interest in the future of the project site, as it is directly south of Elizabeth Park (*Elizabeth Park* | *Public Services*, n.d.). As a result, any connection between the two sites would likely require discussion with Wayne County Parks & Recreation, making them a key stakeholder. Part of the Detroit International Wildlife Refuge is located to the south of the project site, though not directly adjacent. If a connection were to be possible, this would make the Detroit International Wildlife Refuge a key stakeholder, similar to Wayne County Parks & Recreation. The presence of U.S. Fish and Wildlife at the Detroit International Wildlife Refuge would also likely indicate that they have an interest in the future of the project site, which could potentially minimize human use or access.

Another stakeholder with potential to connect to the project site in the future would be the Downriver Linked Greenways Initiative. Their North-South Trail runs along Jefferson Avenue to the west of the former TCPP, and it is reasonable to assume that the Downriver Linked Greenways Initiative would have an interest in any possible connections from the project site to this trail. Additionally, they, and current users of their trail systems, likely would be in

favor of any additional greenway within the site itself, which is a bias to keep in mind when considering future uses of the site.

Current users of the trail systems could include “Healthy Trenton”, listed as a walking group under Beaumont’s Walking Groups, or the “Walk Michigan” program on the Trenton Parks & Recreation website (*Walk Michigan*, 2025; *Walking Groups*, 2024). Though more groups certainly could exist, from the presence on the Trenton Parks & Recreation page, there is an indication for a preference for trails in future uses of the project site. The trail users could also include bikers, and so considering what bike opportunities may exist would be important for them. Additionally, part of the project site is adjacent to the Detroit River, and there is a large fishing and boating presence along the river when seasonally available. These groups would have an interest in promoting boating or fishing along the edge of the site where it meets the river.

An important stakeholder group to note is the Wyandot of Anderdon Nation, members of the Wyandot who remained in Michigan. Given their historical ties to the region, as discussed earlier, they would be an important group to contact and include in engagement strategies, if they so desired. When envisioning future uses, they could provide important historical context beyond the timeline of the TCPP and help to envision new pathways forward for the site.

There are a few additional groups to note as potential stakeholders for the project site. Communicating with the Trenton public school system could provide insight into how the site could act as a potential learning tool for students, or what families in the area would desire at a site like the project site. The Trenton Historical Society could be another stakeholder group to consider the historical context of the site, and could additionally tie to any potential learning opportunities. About a quarter of the population in Trenton is above the age of 65, and the insights that this group offers would be similarly valuable to see what their desires of the project

site would be. A final stakeholder group would be in neighboring Grosse Ile, where the Water's Edge Country Club sits directly across where the eastern part of the project site runs along the Detroit River. This group would likely have strong opinions about what aesthetically is placed on the site that faces them.

There is a wide variety of potential stakeholders for future uses or plans for the project site, and likely more than what is discussed here. Many of them have their own biases, such as walkers, bikers, or the Downriver Linked Greenways Initiative likely desiring more trails in the area, that would be important to consider. Making contact with all of these groups would be important when planning real-world community engagement. For purposes of this project, the assumed biases and desires of the stakeholder groups identified above can be used to inform the design scenario.

Demographic Context

Looking at the demographics of Trenton and surrounding areas can help understand the modern community around the project site and potential stakeholders in more detail. 88.1% of Trenton is “white alone, not Hispanic or Latino” (U.S. Census Bureau, 2024). The median income in 2022 was \$74,267, which was about \$300 less than the U.S. median in 2022 (Creamer & Unrath, 2023). It is important to note that about 24% of the population is 65 or older (U.S. Census Bureau, 2024). Neighboring Grosse Ile had about the same percentage of individuals identifying as “white alone, not Hispanic or Latino”, and a median income in 2022 of \$125,469 (U.S. Census Bureau, 2024). While some demographics are fairly similar between these two cities, the difference in income is stark.

These similarities and differences may affect how the project site could serve community members, and how different communities may have different desires. The larger Wayne County

area had about 48.7% individuals identify as “white alone, not Hispanic or Latino” and a median income in 2022 of \$57,223 (U.S. Census Bureau, 2024). In addition, there is a large difference in median income between the larger Wayne County area and Trenton. While Trenton is generally around the U.S. median income, the lower median in Wayne County indicates that many county residents have lower incomes than those in Trenton. These demographics help to give an understanding of Trenton, and surrounding areas, especially when taken into consideration with the historical context.

Environmental Justice Concerns

Environmental justice considerations for Trenton, Michigan, can be better understood using the U.S. EPA’s “EJScreen” tool, which can provide an environmental justice screen for locations (U.S. Environmental Protection Agency, 2024).

SELECTED VARIABLES	VALUE	STATE AVERAGE	PERCENTILE IN STATE	USA AVERAGE	PERCENTILE IN USA
ENVIRONMENTAL BURDEN INDICATORS					
Particulate Matter 2.5 ($\mu\text{g}/\text{m}^3$)	9.04	7.84	79	8.45	75
Ozone (ppb)	69.3	67.3	70	61.8	84
Nitrogen Dioxide (NO_2) (ppbv)	7.8	7.7	51	7.8	52
Diesel Particulate Matter ($\mu\text{g}/\text{m}^3$)	0.161	0.116	78	0.191	51
Toxic Releases to Air (toxicity-weighted concentration)	3,200	2,500	83	4,600	80
Traffic Proximity (daily traffic count/distance to road)	590,000	910,000	50	1,700,000	43
Lead Paint (% Pre-1960 Housing)	0.5	0.38	66	0.3	73
Superfund Proximity (site count/km distance)	0.91	0.28	91	0.39	90
RMP Facility Proximity (facility count/km distance)	1.1	0.38	90	0.57	84
Hazardous Waste Proximity (facility count/km distance)	3	2	70	3.5	67
Underground Storage Tanks (count/km ²)	7.6	7.6	65	3.6	86
Wastewater Discharge (toxicity-weighted concentration/m distance)	55000	880	99	700000	96
Drinking Water Non-Compliance (points)	0	0.39	0	2.2	0
SOCIOECONOMIC INDICATORS					
Demographic Index USA	0.59	N/A	N/A	1.34	20
Supplemental Demographic Index USA	1.29	N/A	N/A	1.64	34
Demographic Index State	0.61	1.18	28	N/A	N/A
Supplemental Demographic Index State	1.14	1.5	32	N/A	N/A
People of Color	12%	26%	42	40%	24
Low Income	17%	31%	32	30%	33
Unemployment Rate	3%	6%	43	6%	47
Limited English Speaking Households	1%	2%	75	5%	58
Less Than High School Education	4%	9%	37	11%	33
Under Age 5	4%	5%	47	5%	46
Over Age 64	24%	18%	74	18%	77

*Diesel particulate matter index is from the EPA's Air Toxics Data Update, which is the Agency's ongoing, comprehensive evaluation of air toxics in the United States. This effort aims to prioritize air toxics, emission sources, and locations of interest for further study. It is important to remember that the air toxics data presented here provide broad estimates of health risks over geographic areas of the country, not definitive risks to specific individuals or locations. More information on the Air Toxics Data Update can be found at: <https://www.epa.gov/haq2/air-toxics-data-update>

Figure 7: Taken from the EJScreen report for Trenton, MI, this shows the different indicators measured and how Trenton compares both within Michigan and nationally (U.S. Environmental Protection Agency, 2024).

Trenton is generally above the 50th percentile for environmental burden indicators relating to air emissions (Figure 7), which is most relevant to this project. This is because, when considering the future use of the site of a former coal-fired power plant, it likely contributed to the air quality in the area. While other green spaces exist, providing additional green space could be one way to mitigate the past harmful impact that the TCPP, and other industrial uses, have had on Trenton's air quality. Of course, this is not the only solution, especially given the proximity the site has to major roads. As a result, additional caution could be taken to minimize exposure to traffic and the emissions it typically creates from any human uses proposed for future site designs.

Habitat Context

Due to the rich biodiversity within and around the site, assessing habitat potential for species conservation became a major priority for the alternative scenario. U.S. Fish and Wildlife Service data show that about 585 species of flora and fauna are present in the Detroit River habitat. Several species of wildlife are highlighted as important to the ecological health of the Detroit River in the book *The Detroit River, Michigan: An Ecological Profile* (Manny et al., 1988). The river supports a variety of species across different trophic levels, and some key species include fish, birds, invertebrates, and aquatic plants and detritus (Manny et al., 1988). Fish critical to the river's food web are lake sturgeon, walleye, smallmouth bass, and northern pike (Manny et al., 1988). The river is a crucial stopover for migratory birds, including the canvasback duck and common tern (Manny et al., 1988). Benthic invertebrates play a vital role in nutrient cycling and serve as a food source for fish and waterfowl (Manny et al., 1988). The base of the food web includes aquatic plants and detritus, which supports the nutrient-rich ecosystem of the river (Manny et al., 1988). A rough illustration of the trophic pyramid of the

Detroit River ecosystem which contains a sample of species as iterated in the *The Detroit River, Michigan: An Ecological Profile* can be seen in Figure 8.

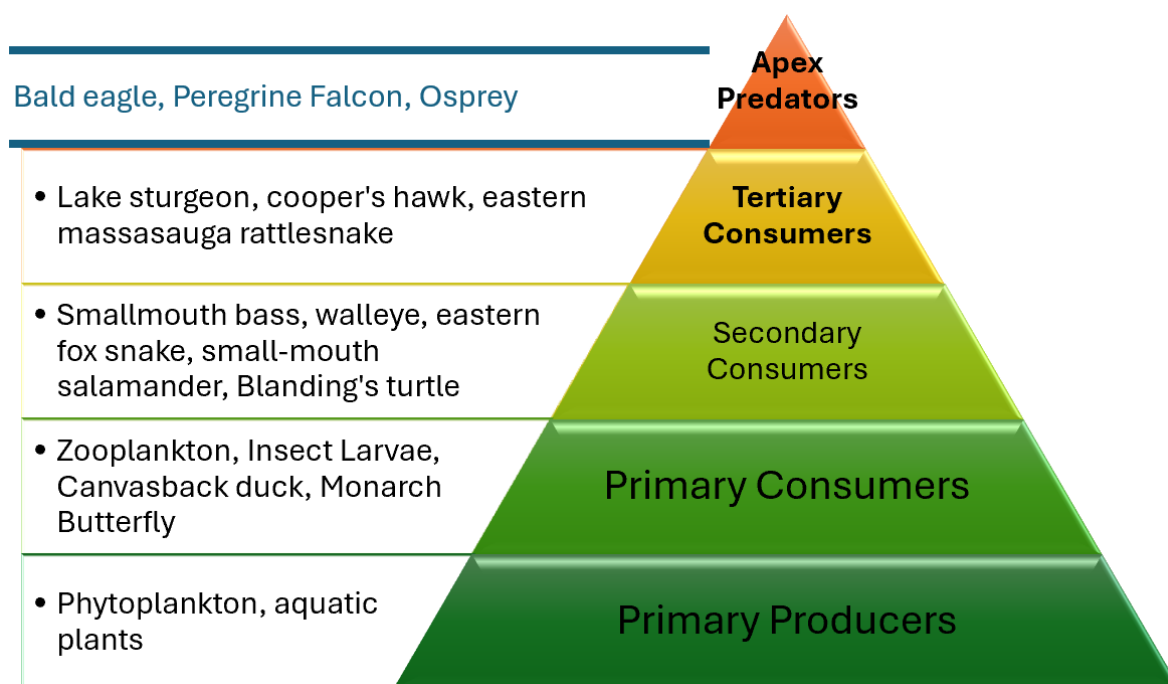


Figure 8: Detroit River Ecosystem food pyramid illustration (Manny et. al, 1988)

The ecological profile assessment in the book also discusses the importance of wetland areas around the river, which provide habitat for amphibians and support various ecosystem services (Manny et al., 1988). The report emphasizes the need to manage human activities like industrial discharges and dredging, as these threaten the delicate balance of the river's ecosystem (Manny et al., 1988). Some species that are known to inhabit the Detroit River throughout the year are detailed below in Table 1.

Species	Detail on habitat in Detroit River ecosystem
Yellow Perch (<i>Perca flavescens</i>)	A common species in the river, known for its adaptability to various environmental conditions.
Walleye (<i>Sander vitreus</i>)	Inhabits the river year-round, with significant spawning runs in spring.
Smallmouth Bass (<i>Micropterus dolomieu</i>)	Prefers the river's rocky substrates and is present throughout the year.
Channel Catfish (<i>Ictalurus punctatus</i>)	A bottom-dwelling species found consistently in the river.
Mallard Duck (<i>Anas platyrhynchos</i>)	Commonly found along the river's shores year-round.
Canada Goose (<i>Branta canadensis</i>)	Commonly found along the river's shores year-round.
Mute Swan (<i>Cygnus olor</i>)	Occupies and defends territories year-round, especially in high-quality habitats.
Muskrat (<i>Ondatra zibethicus</i>)	Inhabits the river's wetlands and is active year-round.
Beaver (<i>Castor canadensis</i>)	Present along the river, contributing to habitat modification.

Table 1: Information on where some species that inhabit the Detroit River throughout the year live.

Located adjacent to the Detroit River and roughly a half-mile north of the Detroit International Wildlife Refuge (Figure 2), the project site has immense potential to serve as a habitat for many species of interest alongside those listed above, particularly those native to the Detroit River area. This includes but is not limited to: Canvasback duck (*Aythya valisineria*), lake sturgeon (*Acipenser fulvescens*), Eastern fox snake (*Pantherophis vulpinus*), and Cooper's hawk (*Accipiter cooperii*) (US Fish and Wildlife Service, n.d.).

The habitat provided by the Detroit International Wildlife Refuge is critical for the many species that live in the Detroit River ecosystem. As the project site is north of some of the refuge parcels, creating a proper habitat for present species is important to keep in mind when considering future uses for the site.

Site Analysis

Possible Site Contamination

The TCPP site features several related parcels purchased by DTE Electric around 1924. Before its development as a power plant, the area was mainly used for agricultural purposes and consisted of marshland. In 1922, the marshland was filled, likely to improve the property's elevation and prevent flooding, though the exact materials used for this fill are unknown (DTE Electric Company, 2021).

The land is primarily flat, with a slight incline toward the southeast, directed toward the Detroit River (DTE Electric Company, 2021). It stands roughly 590 ft above mean sea level. Rainwater is mainly handled by natural absorption, with some storm drains located around the TCPP buildings and culverts in the northern areas of the site. The soil at the location mainly consists of non-native fill, which sits above layers of native peat, gravel, silt, and/or clay. This fill includes sand, silt, and/or clay in many sections, frequently mixed with concrete, brick, wood, coal, and coal ash. The site's hydrogeology is mainly affected by the Detroit River, which flows southward toward Lake Erie, as well as the Slocum Canal, a river branch. Shallow groundwater can typically be found at depths between approximately 4 and 15 feet below ground surface. The depths and availability of groundwater may vary due to the presence of unconsolidated silt and clay in the subsurface. While further investigation is needed to determine

the exact direction of groundwater flow, it is generally believed to move toward the Trenton Channel of the Detroit River and/or the Slocum Canal (DTE Electric Company, 2021).

Based on the history of site operations, several areas within the TCPP property have a higher potential for contamination. The eastern portion of the site, which consists of filled marshland and a former river channel, is more likely to contain contaminants. The source and nature of the fill material used are unknown, raising concerns about the possible presence of hazardous substances. Areas related to the historical storage of petroleum products are potential hotspots for contamination. This includes the vicinity of a former aboveground storage tank (AST), the area around a former underground storage tank (UST), the location of a former 800,000-gallon fuel oil AST north of the plant, the area around the Bulldozer House, which contained remnants of a 10,000-gallon fuel oil AST, and the vicinity of a former UST for gasoline. The locations associated with former coal storage piles, coal handling equipment, and coal ash piles/basins are also likely to have elevated contaminant levels. Coal-related activities often result in the release of various pollutants into the environment. Areas where electrical equipment containing PCBs, such as electrical mats, is used pose a risk of PCB contamination. PCBs are persistent organic pollutants that can accumulate in the environment and pose health risks. Locations associated with the operations of the wastewater treatment plant may also contain higher levels of contaminants, as wastewater treatment processes can generate and release various pollutants.

According to Verma et al. (2016) and Luqman et al. (2024), the potential contaminants of concern at the TCPP site can be organized into the categories of heavy metals and PAHs. Heavy metals are a major concern due to the impacts of coal combustion and fly ash disposal. Both studies identify several key contaminants.

Lead (Pb)

Lead is a significant pollutant in coal, fly ash, and nearby soil. A study of the Sahiwal Coal Fired Power Plant (SCFPP) showed that Pb concentrations in topsoil within a 40 km radius were significantly higher than normal background levels (Luqman et al., 2024). Similarly, research on the Parichha Thermal Power Plant found that groundwater contamination had Pb levels surpassing WHO guidelines, which poses serious health risks, including damage to the kidneys and liver and adverse effects on the circulatory and nervous systems (Verma et al., 2016). These findings suggest that similar contamination could occur at the former TCPP site.

Nickel (Ni), Chromium (Cr), Manganese (Mn), and Iron (Fe)

Both studies indicate elevated levels of these metals in coal, fly ash, and their surrounding environments. Groundwater samples from near the Parichha plant showed high concentrations of these metals, while the SCFPP's topsoil was enriched with Fe due to fly ash deposition (Luqman et al., 2024; Verma et al., 2016). Although these metals naturally occur, they can pose risks at high concentrations.

Potential Sources of Contamination at TCPP

The risk of these contaminants being present at TCPP is further supported by specific site characteristics and historical activities. Sources of heavy metal and inorganic contamination include coal storage piles, handling equipment, and areas designated for ash disposal. The site's eastern section was previously marshland but has since been filled with unidentified materials, raising further concerns about heavy metals and other pollutants. Past petroleum storage tanks and their associated pipelines might have contributed to contamination; however, the specific contaminants linked to these sources are not detailed in the studies referenced. Research conducted by Gupta et al. (2022), Verma et al. (2016), and Agrawal et al. (2010) sheds light on

the important issue of possible contamination at the former TCPP site, emphasizing the need for improved practices in coal combustion and waste management.

Potential Extent of Heavy Metal Contamination

Studies suggest that the impact of coal-fired power plants can extend several kilometers. For instance, the Singrauli study identified elevated levels of heavy metals such as cadmium, lead, arsenic, and nickel within a 2–4 km radius, with concentrations gradually declining between 6–8 km (Agrawal et al., 2010). Additionally, the connection between groundwater contamination near the Parichha plant and its proximity to ash ponds highlights the importance of considering groundwater flow and soil characteristics in mitigating leachate migration (Verma et al., 2016). Investigations at the Parichha plant revealed that heavy metals in fly ash might be significantly more concentrated than in the feed coal, with certain substances like lead and chromium exceeding the WHO's groundwater limits (Verma et al., 2016). Similarly, the Singrauli region's soil samples indicated heavy metal concentrations, particularly arsenic and lead, that were notably above background levels in areas closest to the power plants (Agrawal et al., 2010). These findings suggest the necessity for more effective monitoring and management strategies.

The studies also highlight the role of wind in pollutant dispersion. The research in Dadri noted that arsenic deposition was more significant in villages aligned with the wind direction, with contamination levels decreasing with distance from the plant (Gupta et al., 2022). This information can guide future planning to minimize exposure and protect communities.

Lastly, the persistence of contaminants in environmental systems is a key takeaway from these studies. Groundwater near the Parichha ash pond remained impacted long after disposal, due to ongoing leaching of toxic elements from fly ash. This underscores the necessity for

continuous monitoring and proactive measures to safeguard water quality and public health (Verma et al., 2016). Historical coal storage and handling at the TCPP, along with wind patterns and coal ash disposal areas, likely caused contamination beyond the facility. Furthermore, the marshland or former river channel to the east may further increase contamination risks due to hydrological connections and legacy pollutants unrelated to the power plant's operations.

Polycyclic aromatic hydrocarbons

PAHs are a group of organic compounds characterized by multiple fused aromatic rings (Cheng et al., 2019). These compounds primarily form during the incomplete combustion of organic materials such as coal, wood, and petroleum products. This process is particularly relevant in coal-fired power generation, which continues to be a major energy source for thermal power plants. When coal is burned at high temperatures without complete oxidation, it releases a diverse array of PAHs into the environment. During combustion, coal plants release PAHs into the air as particulates and also deposit them into the soil through ash and other residues (Cheng et al., 2019; Stout & Wasielewski, 2004). These compounds are a major concern because many are known to be toxic, mutagenic, and carcinogenic (Cheng et al., 2019).

Research around coal-fired power plants in Shandong, China, reveals elevated concentrations of four-ring PAHs, including fluoranthene, pyrene, benz[a]anthracene, and chrysene. These compounds not only persist in the environment but also serve as clear indicators of coal combustion. Such insights highlight the need to address the environmental and health risks associated with PAH contamination from coal-fired power plants (Cheng et al., 2019; Stout & Wasielewski, 2004).

Potential Extent of PAH Contamination. The English Station power plant highlights the environmental risks linked to coal combustion (Stout & Wasielewski, 2004). After decades

of operation, there has been significant contamination of surrounding soils with PAHs. This pollution originated from coal combustion residues and dredged sediments used during the construction of the site, demonstrating the cumulative effects of coal-based industrial activities on soil quality over time. The presence of PAHs in various states of weathering indicates both historical contamination and ongoing contributions from the plant's operation. Given the TCPP's similar history, both in terms of operation and the likely use of dredged materials in the filled marshland it was built on, there is a strong possibility of widespread PAH contamination throughout the site, emphasizing the need for proactive monitoring and remediation efforts (Stout & Wasielewski, 2004).

Additionally, the Shandong study showed that PAH concentrations in soil decrease with distance from coal-fired power plants, with the highest levels near coal-handling zones (Cheng et al., 2019). This suggests that areas at the former TCPP site where coal was stored or handled, or where ash was disposed of, are likely hotspots for elevated PAH and heavy metal levels, posing long-term risks to environmental and human health (Cheng et al., 2019). While these studies provide useful insights, there are limitations in applying their findings to the project site. Factors such as coal type, combustion technology, waste management practices, and local hydrogeology affect contaminant distribution. The hydrological characteristics of the TCPP's marshland may worsen contaminant migration compared to the studied sites. Therefore, detailed soil and groundwater sampling is necessary to accurately assess contamination and inform remediation efforts.

Site Name	Location	Similarity to TCPP	Citation
Sahiwal Coal Fired Power Plant (SCFPP)	Sahiwal, Pakistan	High Pb in topsoil from coal combustion; potential for heavy metal contamination similar to TCPP's coal ash areas.	Luqman et al., 2024
Parichha Thermal Power Plant	Parichha, India	Groundwater and soil contamination with heavy metals (Pb, Ni, Cr, Mn, Fe) from coal combustion; similar risk to TCPP's groundwater flow concerns.	Verma et al., 2016
Singrauli Power Plant	Singrauli, India	Heavy metal contamination within 2-8 km from power plant; similar risk zone to TCPP.	Agrawal et al., 2010
Dadri Power Plant	Dadri, India	Arsenic dispersion influenced by wind direction; relevant to TCPP's coal ash handling and site wind exposure.	Gupta et al., 2022
English Station Power Plant	New Haven, Connecticut, USA	Significant PAH contamination in soil from coal combustion residues and dredged materials; similar to TCPP's filled marshland with unknown materials.	Stout & Wasielewski, 2004
Shandong Coal-fired Power Plants	Shandong, China	High soil PAH concentrations near coal-handling zones; contamination levels decrease with distance; similar risk pattern at TCPP.	Cheng et al., 2019

Table 2: Information on the similar sites that were used to inform potential contamination at the project site and the literature referenced for each.

Ecological Status of the Detroit River

Substantial progress has been made in improving the environmental quality of the Detroit River, particularly through pollution control leading to reduced oil pollution, phosphorus discharges, and contaminant level reduction in fish, birds, and sediments. Ecological recoveries have also been made, including the return of many species such as the bald eagle, peregrine falcon, lake sturgeon, lake whitefish, and burrowing mayflies (Hartig et al., 2008). According to research conducted by the Ontario Ministry of Natural Resources and Forestry (2022), the river currently supports a healthy, diverse, and self-sustaining fish community, indicated through lack

of finding of significant shifts toward pollution-tolerant, benthic fish communities, as well as high levels of fish biodiversity including rare species.

Despite this, challenges remain in restoring the Detroit River's ecological functions, especially considering mass industrialization leading to pollution, resistance-based infrastructure that exacerbates flooding and ecological degradation (i.e., dams), and climate change. Due to the effects of urbanization and industrialization, the Detroit River has experienced a 97% loss of coastal wetlands on the U.S. side, with the Canadian side experiencing roughly a 95% loss of its wetlands (Hartig & Bennion, 2017). This is especially concerning given the biodiversity found within the wetlands, as many wetland species exist as metapopulations, relying on occasional migration between local populations. Thus, wetland density and connectivity are critical for the survival of these species (Gibbs, 2000). Gibbs (2020) also suggests that increased urbanization decreases wetland density and increases isolation, which has a severe impact on wetland biodiversity.

During the 1960s, the Detroit River was heavily polluted with oil spills, untreated wastewater, and industrial discharges, leading to the loss of key species (Hartig et al., 2021). By 1985, 55% of the U.S. mainland shoreline was reinforced with steel sheet piling or concrete, which contributed to reducing natural habitats (Hartig & Bennion, 2017). Activities such as shipbuilding, dock construction, and population growth led to significant habitat loss (Hartig & Bennion, 2017). In addition, the introduction of invasive species, such as zebra mussels, round gobies, and phragmites, can disrupt ecosystems and impose economic costs. Invasive species themselves are known to be the leading cause of biodiversity change in the Great Lakes and extinctions in North American freshwater ecosystems (International Association for Great Lakes Research, 2002).

Another challenge in the Detroit River ecological restoration can be attributed to pollutants, especially those that persist in the ecosystem. Toxic substances, such as polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT) residues, affect bird and fish populations due to their persistence (Hartig et al., 2008). According to Baker et al. (2022), there have been over 150 contaminants of emerging concern (CECs) identified as persistent in the Lake Huron and Lake Erie corridor, which is a heavily urbanized area. These contaminants include pharmaceuticals, pesticides, personal care products, and per- and polyfluoroalkyl substances (PFAS). Among the frequently detected substances were synthetic sweeteners, atrazine, sulfamethoxazole, and caffeine. Contaminants predominantly entered the watershed through wastewater treatment plant effluents, combined sewer overflows, and runoff from urban, suburban, and agricultural landscapes. Fine-grained sediments in the river can help accumulate contaminants, particularly in depositional zones. These contaminants have varying effects on different types of biodiversity such as benthic macroinvertebrates, birds, fishes, and clams (Manny & Kenaga, 1991). In general, they affect reproduction and growth rates, and contaminants in sediments are also known to cause tumors in fish (Manny & Kenaga, 1991).

Efforts for ecosystem rehabilitation in the Detroit River area have taken place since the 1980s, one example being the remedial action plan in 1986. This plan focused on setting restoration goals, prioritizing projects, and addressing beneficial use impairments, including loss of fish and wildlife habitat (Hartig et al., 2018). Through this program, 53 soft shoreline engineering projects were implemented to stabilize shorelines and restore habitats. In addition, nine fish spawning reefs were constructed, significantly improving conditions for species such as the lake sturgeon and walleye. Ecosystem restoration projects, such as the ones taking place in the Detroit River, should ideally aim to restore biodiversity, ecosystem processes, and ecosystem

services simultaneously. Collaborative, evidence-based, and adaptive approaches to habitat restoration are important in complex urban-industrial ecosystems like the Detroit River (Hughes et al, 2016).

Habitat Suitability

Habitat suitability plays a vital role in wildlife species' survival and reproductive success, as it provides essential resources for breeding, feeding, nesting, and resting. Each species relies on particular environmental conditions that support its life cycles, including sites for reproduction, food sources, and shelter. Breeding habitats must provide safe locations for reproduction, including nesting structures, sites for laying eggs, or host plants necessary for larvae to develop. Feeding areas should ensure sufficient food sources are available seasonally to support individuals at different life stages. Nesting environments need protection from predators, environmental disturbances, and appropriate substrates for eggs or young animals. Moreover, resting habitats, such as roosting or stopover sites, allow animals to conserve energy, regulate body temperature, and seek protection from adverse conditions, which is especially important for migratory species. The interaction of these four requirements, breeding, feeding, nesting, and resting, influences habitat choices, population dynamics, and conservation strategies, highlighting the importance of habitat preservation for maintaining biodiversity. Recognizing the specific needs of various species across different ecosystems is crucial for creating effective conservation and management plans that uphold ecological integrity and resilience.

For this restoration project, the habitat assessment and design was conducted based on six different species which are native to the area of the Detroit River (further information on the estimated location of each species can be seen in Figure 24). These species were considered due to their different ecological roles and trophic levels within the Detroit River ecosystem. Other

considerations were based on interviews and discussions conducted with the U.S. Fish and Wildlife Services and Detroit International Wildlife Refuge.

Bald Eagle Habitat Assessment

Bald eagles (*Haliaeetus leucocephalus*) are known to occupy a wide range of habitats, from coniferous forests to shorelines and other aquatic habitats. These aquatic habitats encompass areas such as marine shorelines, estuaries, rivers, and lakes (Garett et al., 1993). For bald eagles nesting in the Pacific Northwest region, their home ranges typically overlap the shoreline interface to include open-water areas and timbered up-land habitats, usually containing mature or old growth trees (Anthony et al., 1982).

Habitats of bald eagles, particularly old growth forests and areas near coastal wetlands, are currently threatened by increasing demands for human development and recreational activities (McGarigal et al., 1991). Reasons for the long-term decline of eagle populations include reproductive failure from contaminants, logging activities that lead to destruction of perch sites and nesting habitats, human disturbance resulting in abandonment of nesting grounds, and habitat losses from urban development (Wood et al, 1989). Understanding the components and important features of the bald eagle habitat is paramount in their conservation efforts.

According to studies by Garrett et al. (1993) on the home range and habitat use of bald eagles, specifically in the Columbia River estuary, resident pairs had an average home range of 22 km², with key foraging areas concentrated in old-growth forests, river islands, and tidal flats.

Breeding. The breeding success of bald eagles is significantly affected by the presence of suitable prey, especially live fish and aquatic birds (Peterson, 1986). As opportunistic feeders, they select breeding locations that provide ample foraging and appropriate nesting environments. They typically build their nests in large trees or snags near water, where undisturbed

surroundings are vital for successful reproduction (U.S. Fish and Wildlife Service, 2007). These birds are susceptible to human activity, necessitating buffer zones of at least 660 ft to avoid nest abandonment and disruptions during the breeding season (U.S. Fish and Wildlife Service, 2007). During this period, mated pairs remain close to their nests, limiting movement to enhance reproductive success, while non-breeding birds show more flexibility in their roosting sites (Watts & Dyer, 2018). The bald eagle's ability to adapt to a diverse set of habitats is partly a consequence of the wide breadth of their food niche that results in their consumption of a wide range of saltwater, anadromous, and freshwater fish, along with numerous species of mammals and birds (Stalmaster, 1987).

Feeding. Bald eagles utilize various hunting techniques, often diving from a perch or mid-air to catch prey from the water's surface (Dunstan, 1985). They prefer areas with water bodies with tall trees or structures for perching, as these spots offer an unobstructed view of their hunting grounds. Their primary diet consists of fish, particularly in shallow waters where the prey is easier to catch (U.S. Fish and Wildlife Service, 2007). During winter, when fish tend to move to deeper waters, bald eagles adapt by hunting waterfowl and small mammals (Watts & Dyer, 2018). They gather in large groups along streams during salmon spawning or near reservoirs and hydropower dams where fish are abundant. Additionally, when other food sources are limited, they scavenge roadkill, landfill waste, and feedlot refuse (U.S. Fish and Wildlife Service, 2007). The seasonal changes in prey availability significantly impact their feeding habits, highlighting their adaptability as opportunistic hunters.

Nesting. Bald eagles generally build their nests close to coastlines, rivers, large lakes, or streams to ensure they can access sufficient food (U.S. Fish and Wildlife Service, 2007). They prefer to nest in mature or old trees, dead trees, cliffs, or high points but have increasingly taken

advantage of artificial structures like power poles and communication towers (U.S. Fish and Wildlife Service, 2007). Their chances of successful nesting increase in areas with low human interference and forest structures that provide stability and easy access to prey (Fraser et al., 1985; Livingston et al., 1990). These eagles depend on large, sturdy trees that offer good visibility and are near water, enhancing their safety and food access (U.S. Fish and Wildlife Service, 2007). Because they are attached to specific locations, preserving the quality of nesting sites is vital for their long-term breeding success.

Generally, spatial use of nesting habitats by raptor birds is affected by territoriality and by proximity and quality of essential nesting components that include nest trees, foraging perches, and availability of prey (Newton, 1979). For bald eagles, characteristics of each habitat, such as the type of prey, type and distribution of perches, and the length and contour of shorelines, might be expected to affect the spatial use and range size of bald eagles that nest in those areas (Watson, 2002).

Wood et al. (1989) found that, based on a study conducted across four major nesting sites and 116 nests in Florida, 97% of nests were found in pine trees (81% found in live pine trees). Nesting trees were slightly taller than the surrounding canopy, although not significantly. Bald eagles generally nest within three km of water bodies (>10 ha). Although bald eagles tolerated some human disturbance, continuous urban presence led to reduced nesting success in some areas based on studies by Wood et al. (1989). This is due to some eagles avoiding urban development areas, despite some studies finding no evidence that human activity (primarily traffic) within 500 m of occupied nests significantly affected reproduction (Fraser, 1985).

Overall, factors such as availability of trees for nesting and perching grounds, proximity to forest areas, and home range sizes are influential in determining the success of the bald eagle

habitat's restoration. Some studies, such as Watson (2002), also recommended a focus on protecting core nesting areas within 600 m of nests.

Roosting. Roosting plays a crucial role in the habitat use of bald eagles, as they rely on mature trees for shelter against wind and severe weather (N.H. Fish and Game, 2010). Roosting locations are often shared among eagles, contributing to increased safety from predators and better resource access through collective foraging knowledge (Watts & Dyer, 2018). The relationship between nesting and roosting areas is vital for efficient movement and resource sharing, highlighting the need to maintain undisturbed roost networks (Watts & Dyer, 2018). Human activities near roosting sites can interfere with feeding and resting behaviors, especially when suitable undisturbed sites are not available; hence, it is critical to reduce disturbances along flight paths and in essential roosting habitats (U.S. Fish and Wildlife Service, 2007). By ensuring connectivity and minimizing disruptions, conservation initiatives can improve the resilience of bald eagle populations and support their long-term survival (Watts & Dyer, 2018).

Bald eagles remain near their nests year-round, and habitat selection varies between breeding and nonbreeding seasons. Although eagles may perch in one habitat while using another (e.g., hunting in mudflats while perching in riparian habitats), accessibility to prey is largely dependent on available perches. Furthermore, perching habitats may be required for other important functions, such as territorial marking and display for potential mates (Fraser, 1981). Meanwhile, Watson (2002) found that the bald eagle's home ranges varied from 2.1 km² (lakes) to 6.4 km² (bays), with habitat structure influencing foraging behavior and prey selection.

Blanding's Turtle Habitat Assessment

Blanding's turtle (*Emydoidea blandingii*) is a semi-aquatic species of special concern in Michigan, where its populations are significantly threatened by habitat loss and human activities.

These turtles, which are known for their long lifespan and dependence on both aquatic and terrestrial habitats, play a crucial role in maintaining the health of wetland ecosystems. However, their slow reproduction rates and sensitivity to environmental changes make them particularly vulnerable to population declines (Congdon et al., 1983; Michigan Natural Features Inventory, n.d.). Blanding's turtles are classified as a species at risk in 17 out of 18 provincial or state jurisdictions in which they are found (Markle & Chow-Fraser, 2014). These issues highlight the urgent need for targeted habitat conservation and restoration efforts to ensure the long-term survival of this species. Refsnider and Linck (2012) found that the presence of multiple wetland types within a landscape, such as lakes, permanent and ephemeral wetlands, is crucial for their survival. Maintaining connectivity between these habitats is essential for vital lifecycle processes, such as seasonal migrations and access to nesting sites.

It is essential to create and restore habitats for Blanding's turtles (*Emydoidea blandingii*) to support their conservation and enhance the health of freshwater ecosystems. Protecting both aquatic and terrestrial habitats ensures that turtles can access critical resources for foraging, basking, nesting, and overwintering (Congdon et al., 1983; Markle & Chow-Fraser, 2014). Blanding's turtles inhabit a wide range of environments, including inland wetlands, coastal wetlands, and upland areas, underscoring the importance of habitat connectivity and diversity for their lifecycle (Markle & Chow-Fraser, 2014). Though composition had some influence in predicting the turtle's home range size, it is not considered a strong predictor (Fortin et al., 2015). Some conditions were exceptions, for example, the presence of agricultural fields increased the turtle's home range size due to having to move more to find resources. In addition, Fortin et al. (2015) showed that unlike other similar species, Blanding's turtles do not always expand their home range size when their habitat is fragmented. This indicates that connectivity

and habitat corridors may be more important than absolute habitat area when preserving the Blanding's turtle population.

Habitat Requirements. *Breeding.* Blanding's turtles depend on upland regions with warm, sunny conditions for effective egg incubation and hatching (Congdon et al., 1983). These environments offer a secure setting with low predation risks and minimal contamination, ensuring the best chances for reproductive success. Males typically exhibit higher activity levels during the period leading up to nesting as they seek mates, while females become more active during the nesting season as they travel to appropriate nesting sites (Markle & Chow-Fraser, 2014). The capability to access both aquatic and land habitats during the breeding season is crucial for the sustainability of the population, underscoring the need to preserve habitat connectivity and minimize human interference in important breeding areas.

Feeding. Blanding's turtles are omnivores, feeding on aquatic vegetation, insects, and invertebrates that flourish in wetland habitats (Markle & Chow-Fraser, 2014). They depend on various aquatic environments, such as shallow wetlands, marshes, ponds, and slow-moving streams, where plentiful vegetation caters to both foraging and basking requirements (Beaudry et al., 2010). Many of the observed study locations were marked by a high concentration of small scrub-shrub and forested wetlands, including wet meadows, vernal pools, and Red Maple swamps, which likely act as primary feeding zones for the turtles (Beaudry et al., 2010). Furthermore, vernal pools offer temporary yet essential feeding areas, providing a dependable food supply, hydration, and shelter during seasonal migrations (Markle & Chow-Fraser, 2014). These varied wetland environments are critical for fulfilling the turtles' dietary needs throughout their life stages. Blanding's turtles require various habitats that include aquatic and terrestrial zones. Their aquatic environments consist of shallow wetlands, marshes, ponds, and slow-

moving streams, which offer abundant vegetation for foraging and basking (Michigan Natural Features Inventory, n.d.).

Nesting. During the nesting season, female Blanding's turtles search for well-drained sandy or loamy soils in upland areas near wetlands, sometimes traveling over 200 meters to find suitable locations (Congdon et al., 1983; Starking-Szymanski et al., 2018; Beaudry et al., 2010). Nests located farther from water sources usually face lower predation rates, as the thick vegetation found in wetlands offers natural protection from predators (Starking-Szymanski et al., 2018). However, nests near roads or shorelines are at a higher risk of predation due to increased exposure to natural and human-related dangers (Starking-Szymanski et al., 2018). In certain instances, turtles utilize human-altered environments such as roadsides and quarries for nesting, highlighting the necessity for conservation measures to reduce risks in these areas (Beaudry et al., 2010). The movements associated with nesting represent a significant part of the upland travel undertaken by breeding females, underscoring the importance of conserving aquatic and terrestrial habitats to ensure successful reproduction (Beaudry et al., 2010). Moreover, Blanding's turtles can also nest in marshes, wet forests, or rocky terrains, showcasing their ability to adapt to various upland habitats (Markle & Chow-Fraser, 2014).

Upland areas adjacent to wetlands are vital for nesting, with females sometimes traveling more than 200 m to find suitable locations with well-drained sandy soils for laying their eggs (Congdon et al., 1983). Many turtles have also been found to select road shoulders, trails, and burned prairie for nesting, with road crossings posing a high mortality risk (Refsnider & Linck, 2012).

Several challenges impact the survival and reproduction of Blanding's turtles. Predation is notable, with up to 82% of nests being destroyed by raccoons, foxes, and other predators,

particularly during the first five days after nesting (Congdon et al., 1983). Habitat loss and fragmentation caused by wetland drainage and land conversion for agricultural or urban purposes decrease the availability of critical nesting and foraging areas (Michigan Natural Features Inventory, n.d.). As previously stated, road mortality is a significant threat especially during the nesting season, as females often cross the roads (Michigan Natural Features Inventory, n.d.). Additionally, human activities, recreational interactions, and environmental shifts, such as changes in temperature and precipitation, further complicate the challenges this species faces.

Resting. Blanding's turtles rely on shallow, vegetated wetlands located near upland regions for vital elements of their life cycle, such as resting, thermoregulation, and shelter (Congdon et al., 1983; Starking-Szymanski et al., 2018). Most turtles also display overwintering habits in shallow wetlands or lakes with adequate vegetation cover.

These wetlands are characterized by dense emergent vegetation like cattails (*Typha spp.*) and floating plants like duckweed, providing essential cover while facilitating foraging (Starking-Szymanski et al., 2018). The turtles prefer wetlands with water depths between 54.5 to 85.8 cm, as these conditions are conducive to basking and effective temperature regulation (Markle & Chow-Fraser, 2014). The connectivity between wetland and upland habitats is vital, as Blanding's turtles migrate seasonally between different areas for foraging, basking, and nesting (Congdon et al., 1983; Starking-Szymanski et al., 2018). Unfortunately, habitat fragmentation caused by urban development and agricultural growth significantly threatens these essential migration routes. Protecting natural wetland-upland transitions and ensuring the presence of undisturbed wetland habitats, such as bogs, is crucial for the species' long-term survival (Markle & Chow-Fraser, 2014).

Sensitivity to the Potential Contamination at TCPP. Blanding's turtle is at considerable risk from pollutants such as heavy metals and polycyclic aromatic hydrocarbons (PAHs). These pollutants are common at sites of former coal-fired power plants, like the project site. These contaminants can linger in sediments and water, posing dangers to reptiles through bioaccumulation and potential toxicity.

Impacts of Heavy Metals. Heavy metals, particularly cadmium (Cd), lead (Pb), and mercury (Hg), are especially concerning. Research on related species, such as loggerhead turtles (*Caretta caretta*), has shown that these metals accumulate in specific tissues, with cadmium and lead having particularly harmful effects on kidney and liver functions. For instance, loggerhead turtle kidneys can contain cadmium levels averaging 31.5 mg/g, indicating a strong potential for bioaccumulation in aquatic reptiles (García-Fernández et al., 2009). Furthermore, cadmium has been proven to be highly cytotoxic in sea turtle cell lines, exhibiting serious adverse effects even at low concentrations (Tan et al., 2009). These studies imply that Blanding's turtles may also accumulate these metals, leading to possible kidney damage, metabolic issues, and weakened immune responses. This concern is amplified by the turtles' long lifespans, increasing their exposure time and the likelihood of cumulative effects.

Concerns About PAHs. PAHs are highly toxic to aquatic life and can significantly impact the development and survival of sea turtle embryos (Alam & Brim, 2000). In research concerning loggerhead turtle eggs, PAHs such as naphthalene and chloronaphthalene were detected at sites in northwest Florida. Although these PAH levels (0.060 to 0.377 µg/g, dry weight) fell below acute toxicity thresholds, they may still present risks for subtle developmental or physiological changes. The possibility of prolonged exposure or synergistic effects with other contaminants, like PCBs and heavy metals, remains a significant worry.

These results are applicable to semi-aquatic turtles like Blanding's turtle, which dwell in similar environments and are vulnerable to PAH contamination. Given their longevity and reliance on aquatic habitats during critical life phases, Blanding's turtles are likely susceptible to PAHs. Even minimal concentrations of these pollutants can disrupt embryonic development or physiological functions, as seen in studies of other turtle species. Moreover, the persistence of PAHs in sediments and their tendency to accumulate increase the risk of lasting exposure for Blanding's turtles, which rely on sediment-rich areas for nesting and foraging.

Given that loggerhead turtles have shown detectable PAH levels in nesting sites less impacted by industry, it stands to reason that Blanding's turtles could also be exposed to comparable or even greater PAH levels. This shows the urgent need for more research into how Blanding's turtles respond to PAH exposure and the potential ecological effects of contamination in their environments.

Wider Ecological Implications. Blanding's turtles residing in remediated coal-fired sites could act as bioindicators for heavy metal and PAH contamination, given the similar ways they may be exposed through contact with sediments, consumption of contaminated prey, and water absorption. The combined impacts of these pollutants highlight the importance of site-specific monitoring and proactive habitat management to reduce exposure risks.

Canvasback Duck Habitat Assessment

Breeding. Canvasback ducks (*Aythya valisineria*) depend on stable wetland environments for effective reproduction, particularly during the breeding season. They search for prairie potholes, freshwater marshes, and smaller wetlands featuring dense vegetation such as cattails (*Typha spp.*) and bulrushes (*Scirpus spp.*) (Soulliere et al., 2007). These habitats provide crucial protection from predators while also ensuring access to the necessary food resources for

raising their young (Soulliere et al., 2007). As migratory birds, Canvasbacks require connections between wetlands and seasonal resource availability to maintain their breeding populations (Kruse et al., 2003). During the breeding period, they tend to choose wetlands with stable water levels, as fluctuations can adversely affect their nesting success. In migration and wintering seasons, they migrate to large, open-water wetlands and coastal estuaries, which serve as vital feeding and resting sites (Soulliere et al., 2007). It is essential to maintain stable wetland ecosystems to support Canvasback populations across their breeding and migratory habitats.

Feeding. Canvasback ducks predominantly eat aquatic plants like wild celery (*Vallisneria americana*), pondweed (*Potamogeton spp.*), and tubers, in addition to invertebrates such as clams and snails that they forage from the water's bottom (Soulliere et al., 2007). These diving ducks require large, open-water wetlands with depths of one to two meters, which enable their unique foraging habits and provide refuge from predators and human activity (Soulliere et al., 2007). The availability of submerged vegetation is crucial for their diet, forming the basis of their feeding behavior. Changes in food availability due to seasonal variations can influence migration patterns and the use of wetlands, making it vital to protect a variety of foraging habitats to ensure healthy populations. Conserving deep-water wetlands with abundant aquatic plants guarantees that Canvasbacks have the necessary resources to meet their energy needs throughout their life cycle.

Nesting. Canvasbacks choose wetlands of moderate size that have emergent vegetation for nesting, preferring areas categorized as Type 3 and Type 4 wetlands (Maxson & Riggs, 1996). Type 3 wetlands, also known as inland shallow freshwater marshes, have standing water at times during the growing season and support plant species such as cattails, bulrushes, and sedges (*Carex spp.*), which are vital for providing cover for nesting females (Maxson & Riggs,

1996). Type 4 wetlands, which have deeper and more stable water levels, offer extra protection by limiting access for land predators and allowing for the construction of floating nests (Maxson & Riggs, 1996). The success of nesting is highly influenced by water stability, with ideal depths between 30 to 68 cm to ensure both nest stability and protection from predators (Maxson & Riggs, 1996). Canvasbacks typically construct their nests among bands of emergent vegetation, where dense plant cover guarantees concealment and stability (Krasowski & Nudds, 1986). Floating nests located further from shorelines face decreased rates of mammalian predation, highlighting the need for choosing nesting sites with effective vegetation cover (Kruse et al., 2003). It is crucial to protect wetlands that combine emergent vegetation with stable water levels to sustain viable nesting habitats for Canvasback populations.

Resting. Resting areas are essential for Canvasbacks, offering protection from predators and environmental disturbances. Clear spaces surrounding nesting areas help lower the risk of mammalian predation, while moderate vegetation density serves to deter avian predators (Kruse et al., 2003). However, variations in water levels and wetland drainage, which are often driven by human activities, can adversely affect nesting success and the availability of habitats, increasing the vulnerability of these birds to hydrological changes (Kruse et al., 2003).

Canvasbacks often occupy the initial site they find during nesting season, which can occasionally lead to less-than-ideal site choices if superior habitats are not accessible (Johnson & Grier, 1988). These ducks prefer stable wetland habitats, such as semi-permanent wetlands with dependable water levels, over temporary or seasonal ponds that may dry up or become unsuitable during a breeding season (Patterson, 1979). As a K-selected species, Canvasbacks prefer to have fewer but higher-quality breeding sites, making habitat stability a critical factor in their reproductive success and long-term population sustainability (Patterson, 1979). Conservation

initiatives should prioritize the preservation of semi-permanent wetlands to guarantee Canvasbacks have suitable resting and nesting sites throughout their life cycle.

Sensitivity to the Potential Contamination at TCPP

A study on contaminants affecting wintering Canvasbacks in the Lake St. Clair and St. Clair River area, focusing on organochlorines and heavy metals, was conducted by Hughes et al. (2014). Based on the study, the key contaminants identified that were thought to have affected Canvasbacks the most are, but not limited to, those displayed in Table 3.

Contaminant Type	Compound	Mean Concentration	Thresholds / Effects
Organochlorines	PCBs	18.15 ng/g ww	No defined toxicity threshold in study
	p,p'-DDE (DDT derivative)	3.10 ng/g ww	No defined toxicity threshold in study
	HCB (Hexachlorobenzene)	7.96 ng/g ww (elevated in some cases)	No defined toxicity threshold in study
	OCS (Octachlorostyrene)	39.10 ng/g ww (significantly high in some birds)	No defined toxicity threshold in study
Metals	Mercury (Hg)	0.58 µg/g dw	- 2 µg/g ww: Adverse reproductive effects
			- 20 µg/g ww: Survival impact threshold (all observed levels below this)
	Selenium (Se)	9.07 µg/g dw	- <10 µg/g dw: Background exposure
			- 10–20 µg/g dw: Elevated levels
			- >20 µg/g dw: Toxicity threshold (3% of birds exceeded this, with one reaching 36.60 µg/g dw)

Table 3: Some of the contaminants that affect the Canvasback duck, the compounds containing them, concentration levels, and thresholds or effects (Hughes et. al, 2014).

Lead is also a heavy metal contaminant of concern found in Canvasback ducks. Levels above 20 ppm in wing bones can be considered significant exposure, potentially due to lead shots (Fleming, 1981). Chronic lead poisoning can be inferred from elevated lead levels in tissues, which are indicative of prolonged exposure (Fleming, 1981). Despite Fleming (1981) failing to explicitly link lead levels to Canvasback mortalities, it is still highlighted how lead poisoning is an important cause of mortality in some waterfowl species.

Lake Sturgeon Habitat Assessment

The book *The Detroit River, Michigan: An Ecological Profile* highlights the lake sturgeon (*Acipenser fulvescens*) as a species critical to the ecological health of the Detroit River. Its role as secondary consumer and as one of the key aquatic predators displays its importance in regulating the Detroit River food web. Despite being considered a native species, lake sturgeons are migratory in nature. Sturgeons, in general, exhibit three general patterns in habitat selection and migratory strategy. Some out-migrate to brackish or estuarine environments after spawning and juveniles follow later, while some out-migrate to the sea immediately, with young and juveniles following. Conversely, a few species remain in freshwater their entire lives (Rochard et al., 1990).

Lake sturgeons themselves are endemic to the Great Lakes basin, and were once abundant in all five Great Lakes and connecting waters. Early reports from U.S. waters of the Great Lakes indicate commercial catch of lake sturgeon ranged from 82,000 kg from Lake Superior to 2.1 million kg from Lake Erie in 1885 (Auer, 1996). In 2022, the population of adult lake sturgeon exceeded 750 individuals, with estimates indicating over 6,000 individuals, indicating successful recovery efforts and stability based on the 2022 Detroit River Area of

Concern Fish Populations Benefit Use Impairment assessment. This was also due to the help of artificial spawning areas (Fabiano & Marklevitz, 2022).

According to Bennion & Manny (2014), only around 3% of area within the St. Clair–Detroit River System meets the depth and velocity criteria for the lake sturgeon spawning habitat. High potential areas include the upper St. Clair River area (near Port Huron, MI), which has the largest suitable habitat areas with natural substrates, along with the middle and lower sections of the St. Clair and Detroit River areas. Chiotti et al. (2023) stated that annual trends and catch rates of the lake sturgeon vary by subpopulation and life stage, influenced by water temperature and location. The stable population trends serve as a baseline for assessing the success of habitat restoration and management efforts. Chiotti et al. (2023) also added that the species' long lifespan is a critical factor in conservation and recovery planning due to their slow reproduction rates and vulnerability to environmental changes.

Breeding. Lake sturgeon depend on interconnected river systems for effective spawning, which underscores the significance of habitat connectivity among wetlands, rivers, and lakes (Damstra & Galarowicz, 2013). In contrast to many fish species, lake sturgeons do not create nests (Damstra & Galarowicz, 2013). Instead, they rely on clean, coarse substrates like cobble and rubble (64–256 mm in size) for their spawning activities (Kerr et al., 2010). Ideal spawning occurs at water temperatures between 10–20°C, with the highest reproductive success recorded at 12–16°C (Kerr et al., 2010). The flow velocity is also vital for egg survival, with optimal spawning occurring at around 0.6 m/s, although sturgeon eggs can be laid within a functional range of 0.03–2.51 m/s; velocities above 1 m/s can decrease egg density (Baril et al., 2017). Juvenile lake sturgeons favor deeper waters (>9 m) featuring sandy or detritus-rich substrates, highlighting the necessity for varied aquatic environments during their early growth (Baril et al.,

2017). Preserving uninterrupted migratory routes is critical for ensuring population stability and reproductive success, as habitat fragmentation can significantly hinder their access to suitable spawning locations (Damstra & Galarowicz, 2013).

Feeding. Lake sturgeon are benthic feeders that choose habitats based on substrate types, favoring soft materials like silt, mud, and sand, which provide the benthic prey they consume (Damstra & Galarowicz, 2013). Their primary diet includes chironomid larvae, burrowing mayflies (*Hexagenia spp.*), and amphipods, all of which flourish in these substrate conditions (Damstra & Galarowicz, 2013). Lake sturgeon display depth-related feeding patterns, preferring shallow waters (< 2–3 m) for foraging because of their moderate flows and substrates consisting of sand, gravel, and detritus (Kerr et al., 2010). Nevertheless, they exploit a wide range of depths (0.5–13 m), using shallow zones for foraging and deeper areas for resting (Smith & King, 2005; Damstra & Galarowicz, 2013). As a species particularly susceptible to pollution and industrial effects, ensuring clean and unpolluted waters is essential for maintaining their prey populations and overall health (Damstra & Galarowicz, 2013). Safeguarding water quality and preserving diverse substrate types are crucial aspects of conservation efforts aimed at supporting lake sturgeon populations.

Nesting. Although lake sturgeons do not construct nests, their ability to reproduce successfully relies on access to spawning habitats in rivers and migration routes that connect wetlands, rivers, and lakes (Damstra & Galarowicz, 2013). Their migratory behavior has resulted in various patterns of habitat selection, with certain sturgeon species migrating to brackish or estuarine areas after spawning, whereas others stay in freshwater for their entire lifecycle (Rochard et al., 1990). These different migration strategies highlight the significance of preserving diverse aquatic ecosystems to support the various behavioral tendencies within the

species. Habitat fragmentation and limited access to spawning sites due to dam constructions and changes in water flow present major threats to their population sustainability (Damstra & Galarowicz, 2013). The preservation of unrestricted rivers and unobstructed routes is essential for allowing lake sturgeon to successfully complete their migratory and reproductive processes.

Roosting. Lake sturgeon demonstrate seasonal migrations to reach varied habitats for feeding, resting, and spawning, underscoring the importance of maintaining connectivity in habitats (Damstra & Galarowicz, 2013). They move between shallow feeding zones and deeper resting areas in response to seasonal changes and environmental factors. While predator management is not specifically mentioned in the literature, the maintenance of healthy prey populations and high water quality plays a vital role in their overall survival and evasion from predators (Damstra & Galarowicz, 2013). The presence of deep resting habitats holds particular significance for lake sturgeon, as these areas offer protection from environmental disturbances and predation. Safeguarding both shallow foraging areas and deep-water resting locations will contribute to the stability of sturgeon populations amid habitat degradation and human impacts.

Contaminants impacting Lake Sturgeon. Lake sturgeons, being bottom-dwellers and long-lived species, are prone to accumulating toxic substances, such as mercury and PCBs, in their tissues. These chemicals pose significant risks to both the sturgeon and human consumers. High concentrations of contaminants, such as PCBs and DDT, are suspected to impair reproduction. Specifically, PCBs and DDT have been linked to egg viability and survival reduction in sturgeon species (Hay-Chmielewski & Whelan, 1997). For mercury, restrictive fish consumption advisories are issued for tissue mercury concentrations above 0.5 ppm. No-consumption advisories are applied if concentrations exceed 1.5 ppm (Wood, 1993). Areas near

shipping channels are also known to experience prop wash and sediment disturbances, reducing habitat effectiveness (Bennion & Manny, 2014).

Banda et al. (2014) also highlighted the effects of personal care products, especially antidepressants and antibiotics, and how they pose risks to fish behavior, reproduction, and development. Antidepressants and antibiotics may alter predator avoidance, reproductive behavior, and growth. Polybrominated diphenyl ethers could disrupt thyroid hormone production, which is vital for developmental processes (Valenti et al., 2012). Studies suggest that exposures to CECs in general may hinder lake sturgeon recovery efforts.

Other factors that could decrease lake sturgeon populations include habitat degradation, overexploitation, barriers to migration (e.g., the establishment of dams), low reproduction rates, and climate change (Chiotti et al., 2023).

Monarch Butterfly Habitat Assessment

Monarch butterflies (*Danaus plexippus*) are essential pollinators and are well-known for their extensive migrations between their northern habitat in southern Canada and the U.S., where they spend the summer, and their southern habitat in Mexico, where they spend the winter. This journey, which covers thousands of miles, depends significantly on suitable stopover habitats and plentiful milkweed plants (*Asclepias spp.*), the only source of nourishment for monarch larvae (Pleasant, 2017). Monarch populations have significantly decreased in the past two decades due to widespread habitat destruction, primarily from intensified agriculture, urbanization, and climate change (Pleasant, 2017).

Breeding. Milkweed is essential for the reproductive success of monarch butterflies since it serves as the only food source for their caterpillars and provides necessary sites for laying eggs (Pocius et al., 2018; Lukens et al., 2020). Among the different species of milkweed, common

milkweed (*Asclepias syriaca*) and swamp milkweed (*Asclepias incarnata*) are especially significant because of their high rates of larval survival and their common occurrence in conservation grasslands (Lukens et al., 2020). Furthermore, nectar-producing plants are vital for adult monarchs as they help meet their energy requirements during breeding and migration (Pocius et al., 2018). The availability of appropriate habitats is also shaped by water resources, with species like *A. incarnata* thriving in wet areas crucial for developing larvae (Lukens et al., 2020). Ensuring the presence of both milkweed and nectar-rich plants within monarch breeding areas is vital for maintaining their populations and enhancing reproductive success.

Based on Fisher & Bradbury (2023), monarch butterflies are highly mobile and exhibit an open-population structure, thus they are less likely to remain in one patch. If milkweed patches are within their perceptual range (50–125 m), they are more likely to move efficiently between patches, increasing egg-laying success. The restoration of milkweed is critical, as it directly supports the reproductive processes of monarchs. Studies have shown that specific milkweed species, such as *A. tuberosa* and *A. exaltata*, can enhance larval survival and improve adult fitness, making them ideal for use in restoration initiatives (Pocius et al., 2017). Collaborative conservation efforts across the Midwest focus on replenishing milkweed and other plants that benefit pollinators to help counteract the decline of monarchs (Pleasants, 2017).

Studies have shown that egg-laying increases with higher milkweed density and floral richness, with some species such as *Asclepias syriaca*, *A. verticillata*, *Helianthus grosseserratus*, and *Cirsium vulgare* universally preferred (Fisher & Bradbury, 2023). Monarch egg and larval abundance was highest in structured gardens where milkweed was spaced apart from nectar plants, rather than randomly intermixed, with an egg-laying rate 2.5 to 4 times higher than gardens where milkweed was intermixed with other plants (Baker & Potter, 2019). This study

also suggests that milkweed is planted in visible, accessible locations with minimal visual obstruction, contributing to monarch butterfly habitat restoration even in human-dominated environments.

Feeding. Monarch butterflies rely on grasslands rich in milkweed and various nectar-filled flowering plants to complete their life cycle (Pocius et al., 2018; Lukens et al., 2020). While the larvae depend solely on milkweed for nutrition, adult monarchs need a steady supply of nectar from flowers, especially during migration and breeding (Pocius et al., 2017; Lukens et al., 2020). The variety of nectar sources in their environments is critical to ensure an adequate energy intake, which supports their extensive migratory journeys. Conservation initiatives focused on preserving and restoring these flowering resources can significantly improve the resilience of the monarch population across their feeding and migratory territories.

Nesting. Monarch butterflies need nesting environments free from harmful chemicals and pollutants, often found in diverse landscapes such as grasslands, shrub-scrub regions, deciduous forests, pastures, and cultivated agricultural fields. They favor wide grassland corridors that support long-distance migrations and seasonal travel, ensuring connections between breeding, feeding, and overwintering locations (Pocius et al., 2017; Pocius et al., 2018). These continuous habitats are vital for maintaining healthy monarch populations, as habitat fragmentation due to agricultural encroachment and urban development reduces milkweed availability and disrupts established migratory paths (Pocius et al., 2017; Pocius et al., 2018). Safeguarding these corridors and addressing habitat loss is crucial for sustaining stable monarch populations throughout their migratory journey.

Resting. Rest areas are essential for monarch butterflies, especially during migration, when they need access to nectar-rich plants to restore their energy levels (Pleasants, 2017).

Conservation initiatives should boost milkweed numbers and establish early-blooming nectar sources to assist monarchs along their migration routes (Pocius et al., 2017; Pocius et al., 2018; Lukens et al., 2020). In the site-specific context, specific stopover locations, such as Humbug Marsh, support migration by offering necessary resources and helping monarchs find their way through fragmented landscapes (Craves, 2008). Ensuring the presence of these essential resting areas can significantly improve monarch survival rates during their extensive migrations.

Monarch Butterflies in Trenton, Michigan. In Trenton, Michigan, the Humbug Marsh plays a crucial role in the Detroit River International Wildlife Refuge. This area is a vital stopover for migrating monarchs, aiding them as they traverse the fragmented landscapes around the Great Lakes (Craves, 2008). Monarchs need access to nectar-rich plants during migration to replenish their energy. While previous surveys documented high numbers of monarchs in Humbug Marsh, a notable decline was observed in 2008, linked to low breeding success earlier that season (Craves, 2008). The ecological significance of this area is heightened by the limited availability of natural habitats at this crucial migratory crossing point (Pleasants, 2017).

The Decline in Monarch Populations. The dramatic reduction in monarch populations is closely associated with the dwindling numbers of milkweed plants, the only suitable place for them to lay eggs and feed their larvae. Since 1999, more than 850 million milkweed stems have been removed from Midwest landscapes, mainly due to the increased application of herbicides in farming and the transformation of grasslands into cropland (Pleasants, 2017). These losses in habitat, combined with extreme weather patterns and environmental changes, have severely impacted monarchs' reproductive success and survival rates during migration (Craves, 2008).

Beyond their ecological role, monarchs are vital for pollination and supporting biodiversity. The presence of rare species, such as the Russet-tipped Clubtail, in Humbug Marsh

highlights the broader significance of preserving and enhancing pollinator habitats (Craves, 2008). Community-driven initiatives, including urban gardening and monarch tagging programs, contribute to the well-being of monarch populations and encourage public involvement and education.

Monarch Sensitivity to the Potential Contamination at TCPP. Heavy metals such as zinc (Zn), lead (Pb), and cadmium (Cd) are often found in soils affected by industrial activities. Monarch larvae are especially vulnerable to these metals since they can accumulate in milkweed, their exclusive food source. Although zinc is a necessary micronutrient in small amounts, it becomes harmful at higher concentrations. Studies indicate increased zinc levels can decrease larval survival, particularly in environments with insufficient macronutrients. The primary issue stems from oxidative stress, as zinc interrupts normal cellular functions and damages essential biomolecules like DNA and lipids. While zinc can act as both a nutrient and a toxic substance, its presence in polluted areas disrupts this balance, particularly affecting previously nutritionally stressed monarchs (Shephard et al., 2022; Shephard et al., 2020).

The accumulation of heavy metals in the food chain poses another significant concern. Over time, these metals can build up in plants and insects. Monarchs feeding on contaminated milkweed may accumulate zinc in their bodies (Reich et al., 2023). This bioaccumulation can lead to trophic transfer, where predators that eat these monarchs are subsequently exposed to higher concentrations of heavy metals, further intensifying the ecological impacts of contamination.

While research into the effects of PAHs on monarch butterflies is still limited, these contaminants are known to be toxic to many organisms. Since coal-fired power plants can emit PAHs into the environment, it is reasonable to suspect that if the site of a former power plant is

contaminated with these substances, monarch butterflies could face adverse effects. More research is needed to evaluate the susceptibility of monarchs to PAHs and the potential implications of such exposure.

In conclusion, the possibility of zinc toxicity, aggravated by nutritional deficiencies, combined with sublethal impacts on growth and reproduction and the bioaccumulation of heavy metals in the food chain underline the importance of thorough assessments and potential cleanup efforts to safeguard monarch butterfly populations in contaminated areas.

Eastern Fox Snake Habitat Assessment

The Eastern fox snake (*Pantheropsis gloydi*) is a species of snake that primarily inhabits emergent wetlands and adjacent uplands along Great Lakes shorelines and large rivers and impoundments. In Michigan, this snake species' known range is restricted to the shoreline and nearshore areas along southern Lake Huron from Saginaw Bay, along with western Lake Erie and southern Detroit River (Harding, 1997). According to Harding (1997), Eastern fox snakes are usually found near water and can swim long distances in open offshore waters and between islands.

This species of snake has declined in population in many areas where it was once abundant, despite being locally common in areas where extensive habitat is still available. The primary threats to this species are habitat loss and degradation, human persecution, and collection for the commercial pet trade (Lee, 2006). Furthermore, much of the fox snake's habitat has been ditched or drained for agricultural, residential, recreational, or industrial development (Lee, 2000). In recent years, there have been a number of studies aimed at analyzing the fox snake's habitat usage and selection, utilizing methods such as Compositional Analysis and Euclidean Distance Analysis, and radio telemetry combined with spatial analysis

(DeGregorio et al., 2011; Shew et al., 2012). Gathering data for snakes is often problematic because their secretive nature hinders observation and sampling (Gibbons & Semlitsch, 1987). Regardless, detailed data on movements, spatial patterns and habitat use, and identification of important habitat features may inform conservation decisions by improving the understanding of a species' habitat requirements (Shew et al., 2012).

It should be noted that the Western fox snake and Eastern fox snake have similar physiologies, with the difference being geographic distribution and minor anatomical attributes (i.e., dorsal blotches), thus providing a suitable comparative study (Harding & Holman, 2006).

Somewhat similar to Shew et al. (2012), Watson (1995), a study on the Eastern fox snake at Point Pelee National, found a stronger association with shoreline and wetland habitats, rather than upland edges. These snakes demonstrated strong site fidelity, regularly using marshes, dunes, and forest edges, while avoiding open water and dense forests. This study also emphasized the importance of habitat connectivity and movement corridors for the Eastern fox snake, with a minimum of 1.5 km between habitat patches being crucial to allow for movement and genetic exchange (Row et al., 2012). Landscape genetic studies have suggested that habitat loss and fragmentation can impact snake population structure (Clark et al., 2010), hence the importance of protecting habitat connectivity, maintaining edge and wetland environments, and minimizing fragmentation to support fox snake populations.

Breeding. Eastern fox snakes depend on various microhabitats for laying their eggs, commonly choosing locations such as soil, decaying plant material, woody debris, or animal burrows (Lee, 2006). These settings offer warmth and protection, crucial for successfully incubating their eggs. The seasonal migrations between upland and wetland habitats are vital for thermoregulation, feeding, and reproduction, emphasizing the need to maintain interconnected

and intact habitat networks that support their life cycle (Row et al., 2012). In winter, these snakes hibernate in abandoned mammal burrows, muskrat lodges, or similar shelters, illustrating these features' importance for breeding and winter survival (Ernst & Barbour, 1989). Preserving these key breeding habitats is critical for the long-term viability of Eastern fox snake populations. Additionally, Eastern fox snakes are known to breed annually, tending to lay their eggs in late June or July in soil, woody debris, decaying vegetation, or animal burrows.

Feeding. Eastern fox snakes primarily hunt small mammals, particularly meadow voles (*Microtus pennsylvanicus*) and deer mice (*Peromyscus maniculatus*), both of which are plentiful in their preferred environments (Lee, 2006; Michigan Natural Features Inventory, 2009). They also consume bird eggs, nestlings, earthworms, insects, and frogs, making them opportunistic feeders who take advantage of various prey sources (Lee, 2006; Michigan Natural Features Inventory, 2009). According to Harding (1997), their diet mainly consists of small mammals such as voles and deer mice, but they will also eat bird eggs and hatchlings, earthworms, frogs, and insects. The transitional areas between upland and marsh habitats are especially significant for feeding, as they provide a combination of grasses and shrubs that offer cover while facilitating access to prey (DeGregorio et al., 2011). Maintaining these transitional habitats is essential to ensure a sufficient food supply and necessary cover for effective foraging.

Nesting. Eastern fox snakes depend on marshes and the nearby upland edges for crucial resources such as thermoregulation, foraging, and nesting (DeGregorio et al., 2011). Ensuring connectivity between these habitat patches is vital for movement and the sustainability of the population, as habitat fragmentation resulting from agricultural expansion restricts their access to suitable nesting areas (Row et al., 2012). The transformation of wetlands and grasslands into agricultural fields poses significant challenges since these landscapes provide minimal cover and

serve as obstacles to movement (Row et al., 2012). Eastern fox snakes are found in emergent wetlands, managed waterfowl habitats, and the adjoining grasslands and woodlot edges, favoring areas with herbaceous vegetation like cattails (*Typha spp.*) (Lee, 2000). They also show adaptability by utilizing disturbed environments, such as agricultural fields, pastures, woodlots, vacant urban lots, rock riprap, ditches, dikes, and residential areas, highlighting the necessity of preserving diverse habitat options for successful nesting (Harding, 1997).

Resting. Eastern fox snakes choose roosting sites that offer security, thermoregulation, and protection from predators. They tend to avoid deep open water, preferring edge habitats where upland and marsh areas meet, as these locations provide better mobility and concealment (DeGregorio et al., 2011). To reduce the risk of predation, they rely on thick vegetation like shrubs and tall grasses, which offer necessary cover while allowing them to stay hidden (DeGregorio et al., 2011). Secure and sheltered roosting environments are crucial for maintaining stable temperature and humidity, providing insulation against extreme heat, cold, and variations in moisture (Markle et al., 2020). Seasonal changes affect roost site selection, with individuals opting for locations based on the availability of habitats and prevailing environmental conditions (MDNR, 2016). It is essential to protect these resting habitats to ensure their survival, particularly given the increasing disturbances and fragmentation of their habitats. A study conducted by Shew et al. (2012) on Western fox snakes (*Pantherophis vulpinus*) showed that these snakes were primarily associated with wet prairies and wetland margins, preferring areas with dense herbaceous vegetation, while avoiding sparse areas such as agricultural fields, upland areas, and bottomland forest. On a microhabitat scale, they preferred sites with high vegetation density for cover. The presence of logs, debris piles, and dense herbaceous cover was also required.

Thermoregulation is considered an important factor in the snake's ecologic preferences, hence why some studies also suggest that Eastern fox snakes prefer open dry habitats such as prairies, dunes, and old fields, along with the added benefit of easy prey access (Row et al., 2012).

Current Energy Needs

With a better understanding of the possible contamination and habitat needs at the project site, the site analysis concludes with consideration for the energy needs around the site. The project site, and surrounding cities in Wayne County excluding Wyandotte, are served by DTE for electricity (Michigan Public Service Commission, 2024). DTE's fuel mix has 11.86% renewable fuels (DTE Energy, 2024). For comparison, in 2023, about 18.44% of net electricity generated in Michigan was from non-fossil fuel sources (U.S. Energy Information Administration, 2024).

A Michigan state bill passed in 2023 that included a clean energy standard of 50% by 2030 and 60% by 2035 (MCL, 2023). There is a long way to go for most of the state and the fuel mix used by DTE to meet this standard. The current plan by DTE is to have 32% renewable energy and 6% storage by 2029, 42% renewable energy and 6% storage by 2033, and 62% renewable energy and 6% storage by 2042 (DTE Electric, 2022). These dates do not currently align with the standard set by the Michigan legislature, but the bill does not take effect until February 2024, so it is possible that their plan has not yet been updated. It is also possible that DTE plans to purchase renewable energy credits from other generators, as this is another way to reach the standard as set by the Michigan legislature (MCL, 2023). Regardless, any renewable energy generation at this project's site would work towards meeting the clean energy standard

and reducing fossil fuel emissions for Michigan residents. This consideration is important to keep in mind when considering how best to balance priorities for a design scenario.

Design Scenarios

Methods

Overview

This project aimed to explore future options for the decommissioned TCPP, using a scenario-based design methodology. Given the site's industrial background, potential contamination, and proximity to important ecological and community resources, two contrasting scenarios are evaluated: a control scenario and an alternative scenario. This structured approach helped assess trade-offs between human use, habitat restoration, and contamination management.

The methodology began with a literature review on coal-fired power plant remediation, brownfield redevelopment, and habitat needs for at-risk species. Following the literature review, site analyses were conducted using aerial imagery, historical records, and regional environmental data to inform remediation strategies and habitat designs.

Control Scenario: Risk Management-Oriented Design

The control scenario was based on DTE's preliminary redevelopment concept. It focuses on minimizing human exposure to contamination through conventional risk management strategies, primarily soil capping and low-maintenance plantings. This design emphasizes surface stabilization, safe public access, and basic ecological improvements, typically seen in post-industrial site redevelopment. It prioritizes containment over the removal of contaminants.

Alternative Scenario: Habitat Restoration-Focused Design

The alternative scenario aims to maximize the site's ecological potential through more proactive habitat restoration strategies. It includes a variety of remediation techniques, such as

extract-and-haul, electrokinetic remediation, phytoremediation, and sediment capping, to address contamination and create habitats for six species of concern: bald eagle, lake sturgeon, canvasback duck, monarch butterfly, Blanding’s turtle, and eastern fox snake.

This scenario envisions the site as a multifunctional landscape that merges ecological restoration with community amenities and sustainable infrastructure. The habitat design is tailored to species-specific needs and regional conservation goals, while recreational elements like trails and facilities are carefully located to avoid sensitive areas.

Control Design



Figure 9: The control scenario, showing the project site and the path proposed through it.

The control scenario presents a redevelopment plan for the TCPP, utilizing standard strategies for post-industrial or brownfield sites with contamination. Based on DTE’s preliminary design and discussions with their team, the plan prioritizes public safety, risk management, and ongoing maintenance. This approach includes capping contaminated areas and developing durable, low-maintenance landscapes for recreational use.

In this control scenario, areas deemed potentially contaminated will be capped strategically to safely manage contamination risks. Recreational spaces, such as plazas and

pathways, will include layers of clean soil, aggregate, or paved materials to create safe public areas and prevent direct contact with any underlying contaminants. These impervious or semi-permeable surfaces have been specifically selected to reduce dust and limit the potential for runoff-related pollution. Open areas in the control scenario will feature a low-maintenance mix of short grasses suitable for casual recreation. Plantings near ponds and other water features will consist of wetland-edge species that serve as transitional zones, filtering runoff and enhancing habitat diversity. Infiltration basins will be strategically placed to manage stormwater retention and sediment settling, while minimizing the risk of contaminant movement. The arrangement of features and the choice of vegetation in the control design are closely aligned with the site conditions identified during preliminary assessments, particularly the shallow soil profile resulting from remediation. By selecting shallow-rooted and drought-tolerant plant species, the control design addresses the site's physical limits, including the limestone barrier layer and insufficient soil depth. These plants will support surface stabilization and erosion control while aligning with the unique soil chemistry created by the limestone layer.

Overall, the control design prioritizes practicality and safety by integrating remediation strategies and landscape elements that respond to likely historical contamination, promote stormwater management, and enhance public accessibility.

Remediation Strategy

The landscape remediation strategy for the control design combines ecological resilience with effective stormwater management. Considering the site's limitations, including a limestone cleanup layer that restricts soil depth to as little as three inches in some areas, the design uses shallow-rooted, drought-tolerant plants and surface stabilization techniques to ensure the site's long-term stability. The planting selection will focus on species requiring minimal root depth

while providing adequate ground cover to accommodate the shallow soil profile. The planned design will use fine fescues, buffalo grass, and native groundcovers to stabilize the surface without penetrating the limestone barrier, which helps reduce the risk of structural damage. Given that limestone can affect soil chemistry, the planned design will incorporate amendments as needed to balance pH levels and enhance plant viability. The chosen vegetation will be suited to these conditions and have low maintenance requirements, ensuring long-term sustainability.

Effectively managing stormwater is essential for preventing erosion and surface degradation. Infiltration basins and swales will be strategically placed to direct runoff, preventing water from pooling and undermining the shallow soil layer. Permeable paving and gravel trails will further enhance drainage by allowing water to infiltrate the ground instead of collecting on the surface. These features will help regulate water flow across the site while integrating seamlessly with the surrounding vegetation. To ensure surface integrity, the design will avoid significant elevation changes that could cause erosion or instability. Mulching and ground cover will be employed to retain moisture, suppress weeds, and provide extra protection against soil erosion. Regular monitoring will be crucial to identify and address any early signs of erosion, plant stress, or drainage issues before they escalate into significant problems. Integrating these remediation techniques will stabilize the landscape and promote ecological functionality. Carefully chosen vegetation, effective stormwater management, and measures for surface stabilization will ensure the site remains resilient while achieving remediation and sustainability goals.

Alternative Scenario: Emphasizing Habitat Restoration



Figure 10: Alternative scenario design, which emphasizes habitat restoration.

The master plan for the alternative scenario (Figure 10) combines amenities for human use with habitat creation, demonstrating a commitment to sustainable urban design and environmental stewardship. This scenario aims to create a balance between ecological restoration and community functionality.

Ecological Restoration and Habitat Creation

A series of wetlands will be developed, as shown in Figure 10 with the (3), to restore native hydrological functions, providing critical habitats for species such as the lake sturgeon, Blanding's turtle, and Eastern fox snake. These wetlands will also serve as natural stormwater management systems, improving flood resilience and water quality. The site's former coal storage area (Figure 11) will be transformed into ponds surrounded by marsh-edge habitats, indicated in Figure 10 with the (1), (15). This change will create essential buffers for species like the canvasback duck. Transitional zones between aquatic and terrestrial environments will

support species such as the Blanding's turtle and the Eastern fox snake, highlighting a seamless ecological mosaic. The sandy ridge is indicated with a ⑰ in Figure 10. A forested area, indicated in Figure 10 with a ②, will serve as a sanctuary for bald eagles, focusing on preserving mature trees and introducing additional native vegetation to support their nesting and foraging needs. Elevated pathways and observation towers, indicated in Figure 10 with ⑬ and ⑮, will offer visitors immersive experiences in restored habitats while minimizing direct human impact and fostering a connection to nature. The areas surrounding the museum and existing buildings will be landscaped with native plants to support monarch butterflies and other pollinators, contributing to broader ecological health.



Figure 11: Former coal storage areas and usage at the TCPP.

Human Use Amenities

A community center, indicated with a ④ in Figure 10, along with facilities such as tennis courts, pickleball courts (indicated with a ⑥ and ⑦, respectively, in Figure 10), and a skate park (indicated with a ⑩ in Figure 10) promote active and inclusive lifestyles. Turf plazas

(indicated with a ⑲ in Figure 10) and seating areas (indicated with a ⑳ in Figure 10) provide welcoming environments for gatherings, relaxation, and events. A museum (indicated with a ⑧ in Figure 10) will showcase the development of energy technology, offering learning experiences that highlight the shift from traditional coal power to contemporary green energy solutions. A research center (indicated with a ⑱ in Figure 10) will serve as a venue for ongoing research into habitat resilience, bioavailability of pollutants, and environmental monitoring. The waterpark (indicated with a ⑫ in Figure 10) and skywalk (indicated with a ⑭ in Figure 10) are family-friendly attractions that merge recreation with education, providing scenic views and interpretive elements related to ecological restoration.

Sustainability and Contamination Management

Focused remediation techniques will target areas likely affected by heavy metals and PAHs, especially in former coal storage areas and power plant facilities. The canal restoration will include the use of phytoremediation plants and constructed wetlands to improve pollutant filtration and reduce runoff. The research center will manage the ongoing observation of pollutants in soil, groundwater, and waterways, promoting adaptive management and ensuring transparency for the public. Efforts to reforest will help restore ecological balance, enhance biodiversity, and provide long-term benefits for carbon sequestration.

Community Integration and Connectivity

A system of pathways will link the site to nearby parks and the Detroit River, encouraging active transportation and improving wildlife pathways. Towers will offer visitors panoramic views of the restored site and serve as educational points to raise ecological awareness.

In this design scenario, energy is generated from two sources: solar panels installed on building rooftops and micro hydraulic turbines integrated into the municipal water pipeline system. However, the micro turbines are exclusively applied to the segment of the pipeline serving the water park building, where the high daily water demand makes this technology particularly effective. Other buildings do not utilize this technology.

Given that the core objective of this scenario is habitat restoration, centralized battery storage, though announced by DTE for the future of the project site, was not pursued to preserve larger contiguous spaces for wildlife (Owings, 2024). Instead, once environmental remediation is largely complete, future designs may incorporate distributed lithium-ion batteries and supporting enclosures adjacent to buildings equipped with solar panels. This approach would facilitate localized energy storage and consumption, reducing transmission losses while optimizing efficiency.

The generated energy is used to power LED streetlights and buildings, pump and monitor groundwater quality with data displayed in the museum, and support electrokinetic remediation.

Habitat Description for the Alternative Scenario

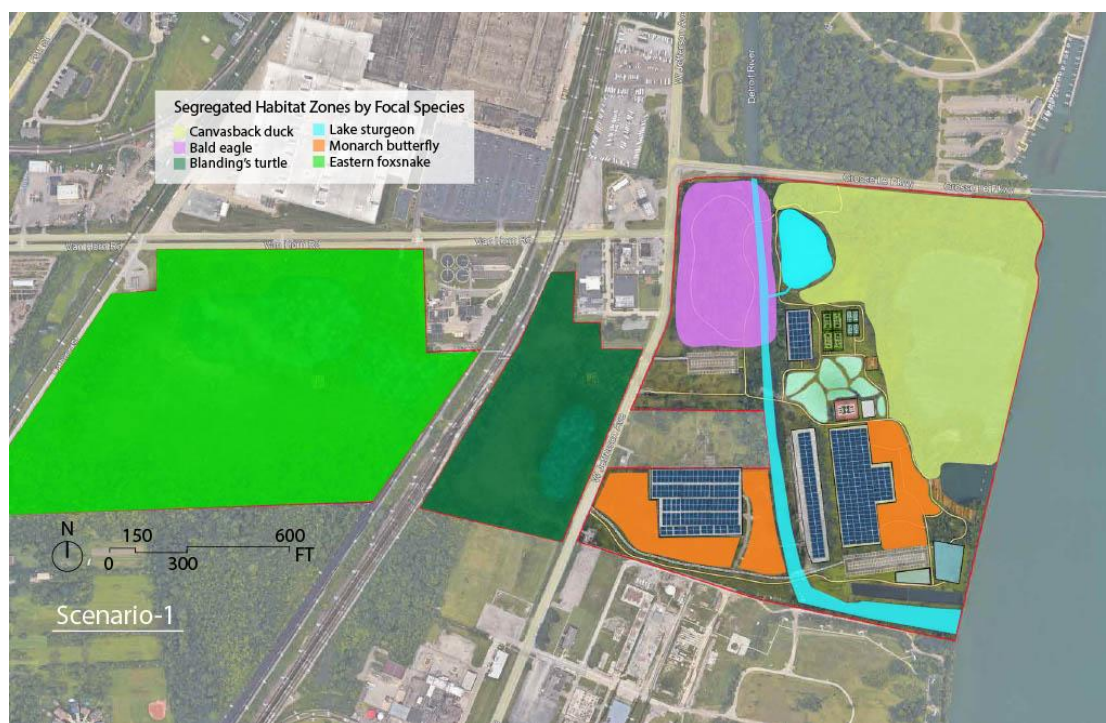


Figure 13: Composite map of primary habitat zones for all focal species.

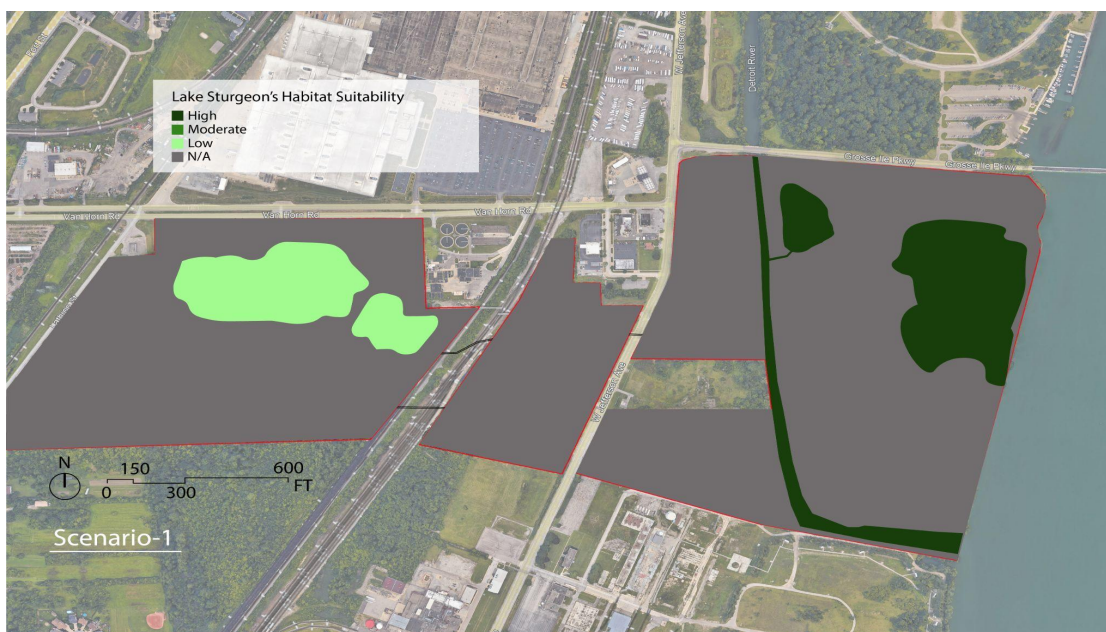


Figure 14: Spatial distribution of suitable habitat for the lake sturgeon.



Figure 15: Spatial Distribution of suitable habitat for the Canvasback duck.



Figure 16: Spatial distribution of suitable habitat for the Eastern fox snake.



Figure 17: Spatial distribution of suitable habitat for the bald eagle.



Figure 18: Spatial distribution of suitable habitat for Blanding's turtle.

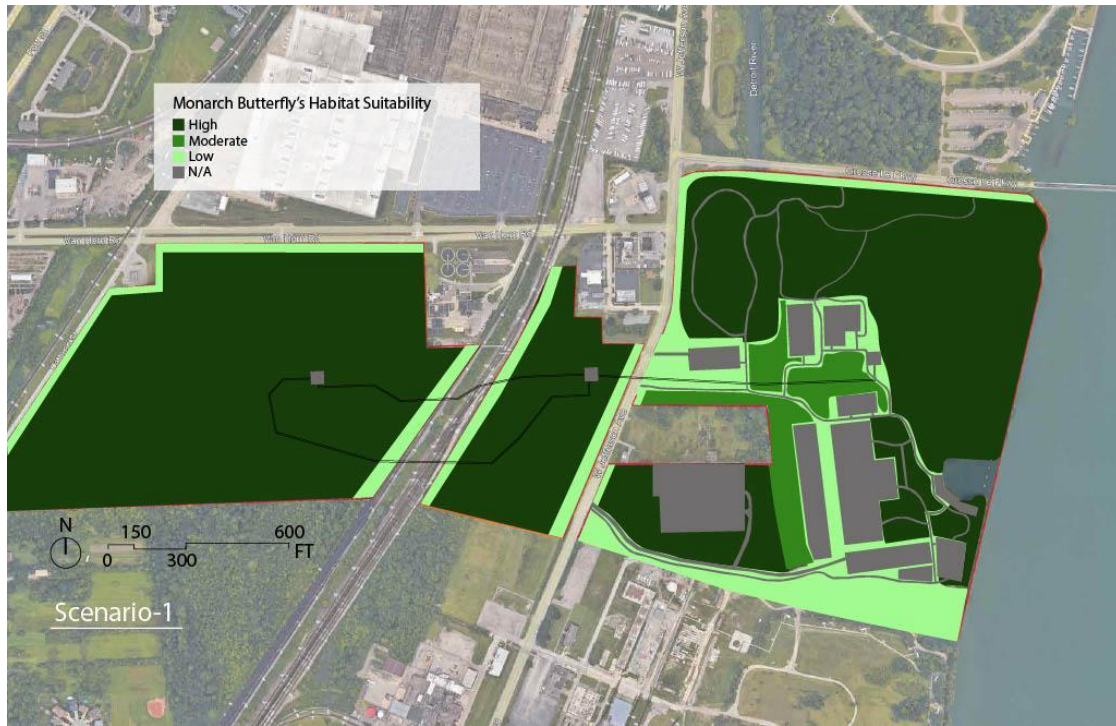


Figure 19: Spatial distribution of suitable habitat for the monarch butterfly.

Monarch Butterfly Habitat Restoration. The habitat for monarch butterflies is designed to facilitate breeding, foraging, and migration by restoring open upland meadows with well-drained, loamy to sandy soils that receive ample sunlight, promoting the growth of milkweed and the availability of nectar (Lukens et al., 2020). These soil conditions allow for good aeration, drainage, and root growth, encouraging a diverse community of native plants. The Dry Sand Prairie supports a variety of species that are beneficial to pollinators, making it an exemplary model for habitat restoration (Michigan Natural Features Inventory [MNFI], 2024c).

The design emphasizes milkweed varieties that have high survival rates to boost monarch reproduction. While common milkweed (*Asclepias syriaca*) is abundant, both swamp milkweed (*Asclepias incarnata*) and butterfly milkweed (*Asclepias tuberosa*) are more successful when introduced via seeding (Lukens et al., 2020). A study by Pocius et al. (2017) indicated that

monarch larvae have higher survival rates (72–75%) when feeding on *A. exaltata* and *A. tuberosa*, which also enhances their physiological well-being in support of migration.

A varied array of nectar-rich wildflowers, including wild bergamot (*Monarda fistulosa*), blazing star (*Liatris spp.*), goldenrod (*Solidago spp.*), and aster (*Symphyotrichum spp.*), guarantees ongoing blooms throughout the season (Lukens et al., 2020). Early-season nectar sources, which are often limited in conservation grasslands, are prioritized to benefit monarchs during their breeding and migratory periods (Lukens et al., 2020).

Pollinator corridors, shown in Figure 20 below, link meadow patches, facilitating monarch movement between feeding and breeding sites. Management approaches such as controlled burns and customized seed mixtures optimize plant establishment, resulting in a robust and high-quality habitat for monarchs (Lukens et al., 2020). By incorporating various research-informed plantings, soil conditions modeled after natural prairies, and habitat connectivity, this restoration offers essential resources for the stability of monarch populations.



Figure 20: Primary habitat zones and pollinator corridor (indicated with yellow arrows) for monarch butterflies.

Eastern Fox Snake Habitat Restoration. The Eastern fox snake (*Pantherophis gloydi*) relies on a combination of emergent wetlands and nearby upland habitats, making the

connectivity of these habitats vital for their movement, foraging, and shelter needs. The wetland area includes emergent marsh, which offers prey availability, protective cover, and sites for thermoregulation (Lee, 2006; Michigan Natural Features Inventory MNFI, 2024a; DeGregorio et al., 2011). Snakes make use of dense plant life, root systems, and burrows found within these wetlands, emphasizing the importance of preserving both wetland and upland elements during habitat restoration (Lee, 2006). Moreover, emergent marshes contribute to ecosystem stability by managing hydrology, minimizing temperature changes, and maintaining a diverse habitat for prey species (MNFI, 2024a).

Emergent marsh ecosystems play a critical role in the survival of the Eastern fox snake, providing ample vegetation cover and food sources. Native wetland flora enhances habitat complexity and structural diversity, which are essential for attracting prey, regulating temperature, and providing shelter. Broadleaf arrowhead offers dense cover and supports the populations of aquatic invertebrates that are food sources for the snake's prey. Pickerelweed aids in soil stabilization within wetlands while providing protective vegetation for hiding. Lake sedge is crucial for stabilizing marsh banks and offers dense ground cover for refuge. Bluejoint grass contributes to the resilience of wetlands and provides a protective vegetative structure for thermoregulation. The restoration plan, by incorporating these emergent plant species, ensures that wetland areas function effectively as shelter and support a rich prey base, making them suitable habitats for the Eastern fox snake (MNFI, 2024a).

The upland habitat corresponds to the Lakeplain Oak Openings ecosystem, characterized as a fire-dependent savanna with sandy, well-drained soils and a variety of oaks, native grasses, and shrubs (MNFI, 2024b). Snakes commonly bask and find shelter in open grasslands and shrubby fringes, highlighting the necessity of maintaining a diverse ground layer for cover and

temperature regulation (DeGregorio et al., 2011). Key tree species in this ecosystem include black oak, white oak, bur oak, and pin oak, all contributing to structural diversity. The understory primarily consists of big bluestem, little bluestem, and switchgrass, which improve the ground cover needed for foraging and refuge.

Ensuring hydrological connectivity is essential for the survival of the Eastern fox snake, allowing access to shallow water areas, basking spots, and overwintering locations, while decreasing fragmentation threats (MNFI, 2024a; Lee, 2006; DeGregorio et al., 2011). Movement corridors that comprise native vegetation and structural habitat elements such as downed logs and root networks facilitate safe travel and reduce the risk of road mortality (Lee, 2006; DeGregorio et al., 2011).

This scenario promotes the long-term viability of Eastern fox snake populations by combining the restoration of emergent marshes with the connectivity of upland savannas and the inclusion of key native plant species. These habitat enhancements provide effective shelter, a rich abundance of prey, and movement corridors, all while bolstering overall ecosystem resilience in post-industrial environments (MNFI, 2024a, 2024b).

Aquatic Restoration for Lake Sturgeon. The habitat for the lake sturgeon (*Acipenser fulvescens*) is structured to facilitate spawning, feeding, and migration by revitalizing deepwater and wetland regions with suitable substrate conditions, improvements in hydrology, and riparian vegetation. Lake sturgeon mainly reside in the benthic regions of large freshwater lakes and rivers, depending on clean, oxygen-rich water and stable substrates for foraging and reproductive activities (Galarowicz, 2003). Spawning takes place over rocky substrates that have interstitial spaces, which aid in egg attachment, provide aeration, and minimize the risks of predation (Auer, 1996b). This design incorporates coarse gravel and cobble beds in nearshore zones while

enhancing water flow to avoid sediment accumulation, which could suffocate eggs and hinder recruitment success (Kempinger, 1988).

Although vegetation is less critical compared to substrate in sturgeon habitats, riparian buffers are vital for enhancing water quality, controlling sediments, and stabilizing shorelines (Auer, 1996a). Riparian species like willows (*Salix spp.*) and sedges (*Carex spp.*) assist in stabilizing riverbanks, trapping sediments, and filtering runoff before it reaches aquatic environments (Galarowicz, 2003). Auer (1996b) highlights the significance of benthic macroinvertebrate availability for the feeding of lake sturgeon, pointing out that habitat degradation leads to a decline in prey populations. Submerged aquatic plants, such as wild celery (*Vallisneria americana*) and common waterweed (*Elodea canadensis*), support these macroinvertebrate populations by offering surface area for biofilm growth and helping to stabilize sediments, indirectly aiding sturgeon by nurturing a diverse and stable aquatic food network. These plants also play a role in oxygenating the water and creating microhabitats for chironomid larvae, burrowing mayflies, and amphipods, which are important prey for sturgeon.

This restoration effort places a high priority on hydrological connectivity between rivers, wetlands, and deep lake regions to guarantee successful spawning and migration. The migratory pathways are shown in Figure 21 below. This connectivity allows sturgeon to reach spawning sites without barriers. Maintaining clean, well-aerated water is crucial for the survival of early larvae, as pollutants and sedimentation can negatively affect recruitment success (Auer, 1996a). By combining substrate restoration, riparian buffer planting, and improvements in hydrological connectivity, this initiative aims to bolster the long-term sustainability of lake sturgeon populations, ensuring their prosperity in a rehabilitated post-industrial environment.



Figure 21: Primary habitat zones and migratory pathways (yellow arrows) for lake sturgeon.

Wetland Restoration for Canvasback Ducks. The habitat for the Canvasback duck (*Aythya valisineria*) is developed to facilitate nesting, foraging, and breeding by rehabilitating shallow freshwater wetlands with ideal vegetation and water conditions. Canvasbacks depend on wetlands that provide a mix of emergent cover for nesting and open water for feeding, choosing locations based on factors like water depth, vegetation structure, and the presence of predators (Kruse et al., 2003; Cornell Lab of Ornithology, n.d.). Their success in nesting is heavily influenced by seasonal water levels, which affect the availability of habitat and risk from predators (Kruse et al., 2003).

Water levels are critical for the nesting success of Canvasbacks, influencing both habitat stability and exposure to predators (Kruse et al., 2003). In prairie pothole regions, elevated water levels reduce mammalian predation, improving nest survival rates. In contrast, snowpack-dependent wetlands like Ruby Lake, Nevada, can experience vegetation loss when water levels rise too high, forcing birds to nest in exposed areas where they are more vulnerable to avian predators such as ravens and gulls (Kruse et al., 2003). Successful nests are typically located

over shallow water, away from the shore, within broad bands of emergent vegetation that provide concealment and structural stability. In the absence of preferred vegetation, birds may resort to suboptimal species like Baltic rush (*Juncus balticus*), which is associated with higher nest abandonment due to insufficient cover (Kruse et al., 2003). This dynamic is addressed in the restoration scenario, where former coal storage areas will be converted into ponds with marsh-edge habitats (Figure 10, ①, ⑮). By managing water levels of the pond, the design aims to promote the growth of stable emergent vegetation that supports successful Canvasback nesting and reduces predation risks.

Choosing the right vegetation is essential for both nesting and foraging purposes (Cornell Lab of Ornithology, n.d.). Hardstem bulrush (*Scirpus acutus*), cattails (*Typha spp.*), and sedges (*Carex spp.*) provide necessary structural support for floating nests, ensuring their stability during fluctuating water levels (Kruse et al., 2003). Canvasbacks mainly feed on pondweeds (*Potamogeton pectinatus*), muskgrass (*Chara spp.*), and native seeds, with their diet supplemented by aquatic invertebrates such as chironomid larvae, caddisflies, damselflies, water boatmen, and snails, which are vital for providing protein, particularly for breeding females (Austin et al., 1990). The design of the wetland incorporates shallow, nutrient-rich areas with submerged plants and organic debris, promoting a diverse population of invertebrates that meet the dietary requirements of Canvasbacks (Cornell Lab of Ornithology, n.d.).

Predation is a significant factor affecting nesting success and varies by wetland type (Kruse et al., 2003). In the prairie potholes, higher water levels serve as a deterrent for mammalian predators, which increases the chances of nest survival (Kruse et al., 2003). However, at Ruby Lake, avian predators are more prevalent, and nests in exposed areas are particularly at risk (Kruse et al., 2003). To reduce the chances of predation, the restoration

approach emphasizes the creation of extensive bands of emergent vegetation, the maintenance of stable seasonal water levels, and the enhancement of structural diversity within the wetland (Kruse et al., 2003; Cornell Lab of Ornithology, n.d.).

By combining considerations of vegetation selection, management of water levels, and measures to reduce predation, this constructed wetland supports a sustainable habitat for breeding and foraging for Canvasback ducks, thereby promoting their long-term survival in a rehabilitated post-industrial environment.

Wetland and Upland Habitat Restoration for Blanding's Turtles. Blanding's turtle (*Emydoidea blandingii*) thrives in habitats that enable foraging, basking, nesting, and overwintering. This is achieved by restoring a mix of emergent marsh, southern wet meadow, and dry sand prairie environments. These ecosystems are vital as they provide necessary resources like food, nesting locations, and pathways for movement, ensuring ecological links between wetland and upland areas (Congdon et al., 1983; Michigan Natural Features Inventory [MNFI], 2024a).

Emergent marshes are essential for Blanding's turtle, serving as key foraging grounds with plentiful aquatic plants and macroinvertebrates. Important plant species such as cattails (*Typha spp.*), buttonbush (*Cephalanthus occidentalis*), and duckweed (*Lemna minor*) offer protective cover, help stabilize sediments, and improve water quality, creating favorable foraging conditions (Starking-Szymanski, Szymanski, & King, 2018; MNFI, 2024a). Other plants like bluejoint grass (*Calamagrostis canadensis*), lake sedge (*Carex lacustris*), and broadleaf arrowhead (*Sagittaria latifolia*) enhance habitat diversity and provide shelter for young turtles (MNFI, 2024a). The restoration of emergent marshes also benefits muskrats (*Ondatra zibethica*),

whose dens turtles often use for refuge and temperature regulation (Starking-Szymanski et al., 2018).

Southern wet meadows adjacent to these marshes create crucial transition areas that assist turtle movement between aquatic and land habitats. Dominated by tussock sedge (*Carex stricta*), swamp milkweed (*Asclepias incarnata*), and joe-pye weed (*Eutrochium maculatum*), these meadows offer seasonal shelter and basking spots while ensuring connectivity between wetland pools and nesting sites (MNFI, 2024e). The presence of marsh bellflower (*Campanula aparinoides*) and bluejoint grass (*Calamagrostis canadensis*) further enhances biodiversity, supporting essential pollinators and insect food for juvenile turtles (MNFI, 2024e).

For Blanding's turtle to reproduce successfully, it is crucial to have dry sand prairie habitats that are well-drained for nesting. Studies indicate that females can travel up to 1,115 m from wetland areas in search of ideal nesting spots with sandy or loose soil (Congdon et al., 1983). In these uplands, plant species like little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), and prairie dropseed (*Sporobolus heterolepis*) play a dominant role while providing minimal shade and maintaining stable soil for incubation (MNFI, 2024b). Additional plants such as wild lupine (*Lupinus perennis*) and hoary puccoon (*Lithospermum canescens*) bolster overall prairie ecosystem health and promote pollinator activity, enhancing biodiversity (MNFI, 2024b).

Predation poses a serious threat to the success of Blanding's turtle nests, with raccoons (*Procyon lotor*) and foxes (*Vulpes fulva*, *Urocyon cinereoargenteus*) causing up to 82% of nest losses (Congdon et al., 1983). To counter these risks, the restoration plan incorporates vegetative buffers and linear corridors for nesting, which help minimize predator exposure while preserving connections between wetland and upland habitats (Congdon et al., 1983). Ensuring stable water

levels in emergent marshes and southern wet meadows also helps prevent flooding of nests and increases habitat resilience (MNFI, 2024a, 2024e).

This approach aims to sustain Blanding's turtle populations by reinstating a varied habitat matrix comprising emergent marsh, southern wet meadow, and dry sand prairie. The combination of aquatic foraging areas, transitional meadows, and open sandy sites for nesting enables turtles to reproduce, migrate, and find refuge successfully in a restored landscape impacted by industrialization (Congdon et al., 1983; Starking-Szymanski et al., 2018; MNFI, 2024a, 2024b, 2024e).

Riparian and Forest Habitat Restoration for Bald Eagles. Bald eagles (*Haliaeetus leucocephalus*) rely on large, mature trees for nesting, perch, and roosting, especially in wooded areas near lakes, rivers, and wetlands (U.S. Fish and Wildlife Service, 2007). Nesting sites are generally found within 200 m of water, providing easy access to fish, their main food source. They favor super-canopy trees that rise above the surrounding forest, allowing for an unobstructed view of the area and offering protection from predators (Grim & Kallemeyn, 1995).

A long-term study conducted in the Superior National Forest revealed that white pine (*Pinus strobus*) was the most commonly utilized nesting tree, supporting 82 out of 102 nests, followed by red pine (*Pinus resinosa*) and aspen (*Populus spp.*), which supported fewer nests (Grim & Kallemeyn, 1995). Similarly, research in the Ottawa National Forest in Michigan found yellow birch (*Betula alleghaniensis*) to be another significant species for nesting trees (Grim & Kallemeyn, 1995). Given these preferences, restoration initiatives should focus on planting and preserving these species to ensure a reliable supply of large, structurally sound nesting trees.

Restoring floodplain forests presents a viable approach for improving bald eagle nesting habitats. These forests supply the large, mature trees essential for nesting and act as a buffer

against human activity. Important tree species include eastern cottonwood (*Populus deltoides*), silver maple (*Acer saccharinum*), and American sycamore (*Platanus occidentalis*), all of which offer suitable nest locations due to their height and robust branch structures (MNFI, 2024d). Black willow (*Salix nigra*) also contributes to stabilizing riparian zones while providing secondary perching options (MNFI, 2024d).

In addition to nesting locations, communal roosting sites are vital for bald eagles, especially during the winter months. Studies have indicated that eagles depend on clusters of tall trees that provide structural stability, favorable positions for maintaining body temperature, and refuge from predators (Watts & Dyer, 2018). These trees are typically located in forested riparian regions with low levels of human disturbance. To support roosting habitats, restoration efforts should focus on conserving and planting green ash (*Fraxinus pennsylvanica*), red maple (*Acer rubrum*), and hackberry (*Celtis occidentalis*), which enhance structural diversity and perching opportunities (MNFI, 2024d). Moreover, buttonbush (*Cephalanthus occidentalis*), swamp rose (*Rosa palustris*), and spicebush (*Lindera benzoin*) can add mid-story complexity and habitat stability to the riparian buffer (MNFI, 2024d).

Creating vegetative buffer zones alongside roads and developed areas is vital for minimizing human disturbance near bald eagle nesting and roosting habitats. While eagle nests are situated high in tall trees, dense plantings of native shrubs, such as buttonbush and swamp rose, can help reduce visual and noise disturbances at ground level. This contributes to a more stable and less disturbed ecosystem. These species, identified in MNFI (2024d) as suitable components of riparian and floodplain forest communities, enhance the overall habitat complexity necessary for long-term nesting success.

By combining floodplain forest restoration, the conservation of mature trees, and the

establishment of riparian buffer zones, this restoration strategy promotes the long-term viability of bald eagle populations. The protection and enhancement of large nesting trees, stable roosting sites, and shielding vegetation buffers will create a resilient habitat, ensuring the ongoing success of bald eagles in a restored post-industrial environment (U.S. Fish and Wildlife Service, 2007; Grim & Kallemeyn, 1995; MNFI, 2024d; Watts & Dyer, 2018).

Remediation Techniques for the Alternative Scenario

This scenario for a redevelopment of the project site employs a comprehensive suite of remediation techniques tailored to restore ecological balance and provide suitable habitats for six focal species. These techniques address likely contamination from past industrial activities, which is understood through a literature review and study of similar sites, while creating diverse and interconnected habitats. The two phases of remediation are shown below in Figure 22 and Figure 23.

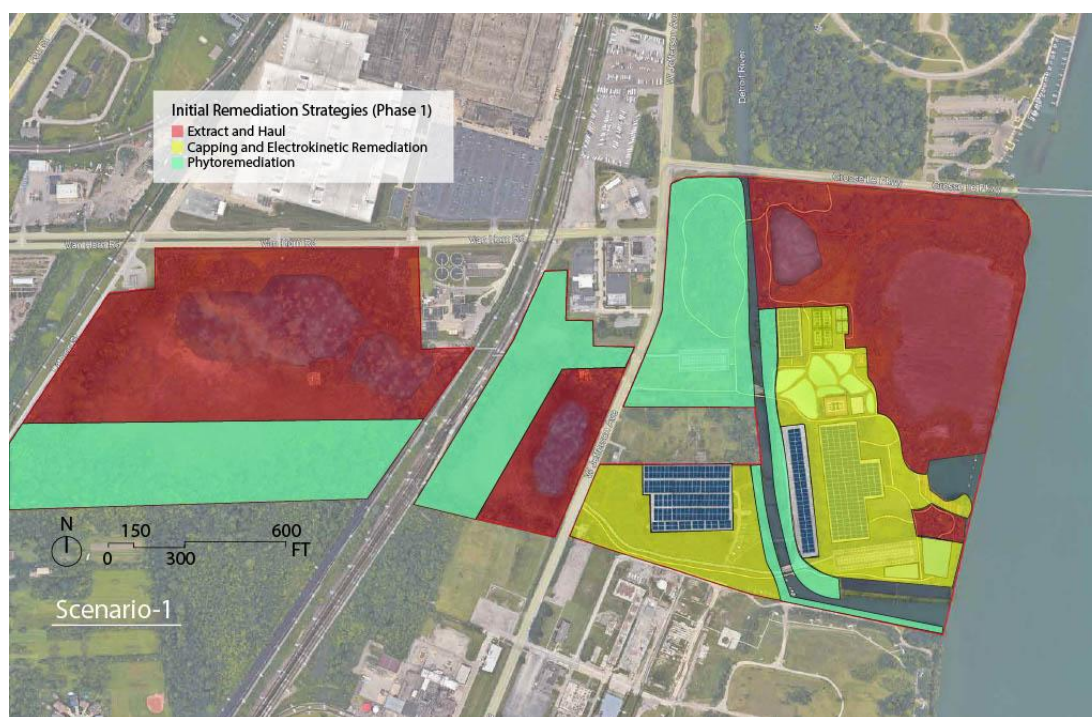


Figure 22: Alternative scenario, with indication for intended remediation techniques during phase 1.

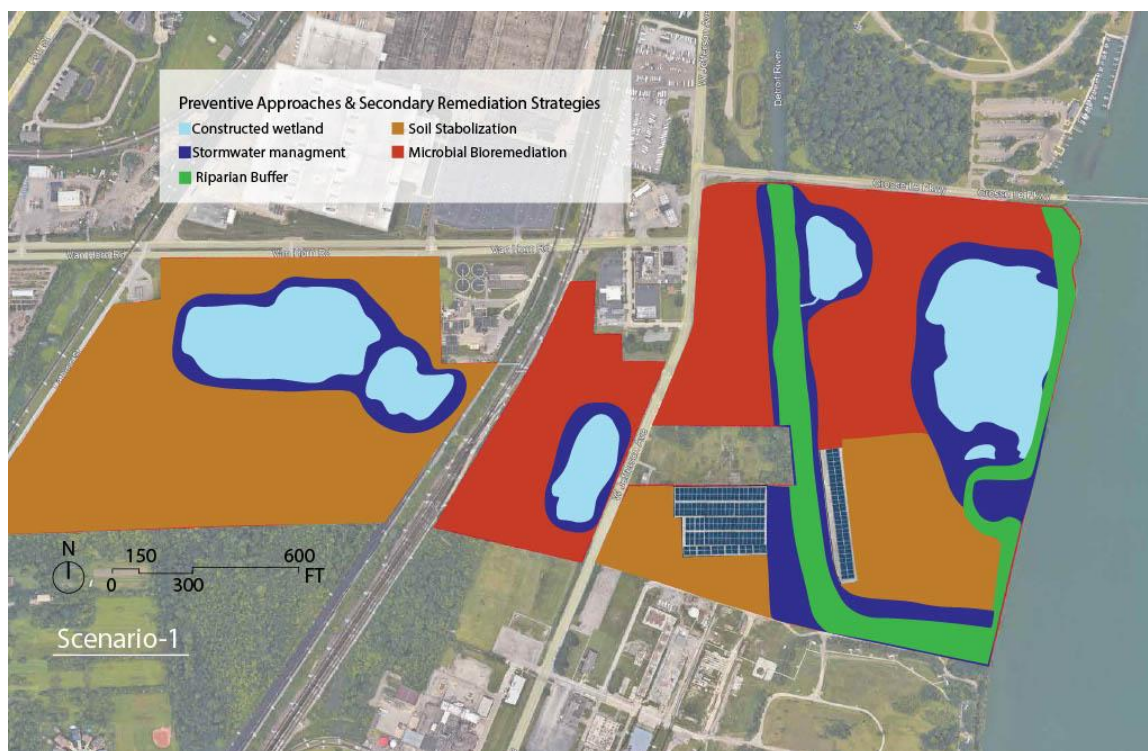


Figure 23: Alternative scenario, with indication for what remediation techniques are intended during phase 2.

Phase 1: Initial Remediation Strategies. *Extract and Haul*. Extract and haul is a remediation technique that removes contaminated soils and sediments from a site and places them elsewhere. This may not fully eliminate contamination, and this method is discussed in greater detail in the literature review for remediation. For the alternative scenario, this method is utilized to eliminate soils polluted with heavy metals, PAHs, and leftover coal combustion byproducts likely built up over many years of industrial operations.

The choice to implement extract-and-haul as a remediation strategy is grounded in a thorough site analysis, which includes reviews of relevant literature on common pollutants found at former coal power plants, historical records of land use, and evaluations of aerial imagery. Studies show that contaminants like arsenic, lead, cadmium, and zinc are commonly found at industrial sites, in addition to PAHs and leftover industrial waste (Guemiza et al., 2017). In light of this, the remediation strategy presumes that contamination is concentrated in particular areas,

such as coal ash disposal sites, industrial fill locations, and sediments close to the shore, designating these sites as priority targets for excavation. Nevertheless, while the extract-and-haul approach effectively removes contaminants from the surrounding environment, it does not fully resolve the contamination issue; instead, it shifts the problem to another location, typically a landfill that will still need ongoing management (Goldenberg & Reddy, 2014).

Acknowledging this limitation, the remediation plan for the alternative scenario seeks to achieve two main goals: protecting the safety of humans and wildlife by eliminating contamination from essential ecological zones and lessening environmental impact by minimizing the total amount of material that needs to be extracted. To maintain this balance, excavation targets only the most contaminated locations while alternative remediation techniques, such as stabilization and sediment capping, are employed where suitable. This strategy aids in reducing unnecessary soil movement, thus lowering the overall carbon footprint related to transportation and disposal.

Excavation sites are chosen based on historical land use, aerial image analysis, and current conditions. Sites previously used for coal storage, waste disposal, or industrial activities are prioritized due to higher contamination risks. Aerial images help identify areas that may have buried contaminants. This approach allows the remediation measure to concentrate on the most critical areas, minimizing disturbance in lower-risk locations.

In addition to eliminating contaminants, the extract-and-haul method is essential for habitat restoration. Several excavated sites are intended for transformation into constructed wetlands and wildlife habitats, fostering a more resilient and ecologically varied environment. Previously used coal ash disposal areas will be converted into constructed wetlands, naturally filtering runoff while offering vital habitats for species like the Canvasback duck. Likewise,

locations adjacent to the water, where sediment quality has been negatively impacted by contamination in the past, will be rehabilitated using clean, rocky materials to establish spawning areas for lake sturgeon. In the upland regions, excavation and regrading activities will facilitate the creation of nesting and basking spots for Blanding's turtles and Eastern fox snakes, with sandy and vegetated areas designed to meet the ecological requirements of these species.

By combining extract-and-haul remediation with habitat restoration, the remediation plan for the alternative scenario would remove potential contamination and guarantee that the landscape is reshaped for enduring ecological sustainability. This approach recognizes the natural constraints of excavation as a remediation strategy while strategically utilizing the disturbed area to promote wildlife conservation and habitat connectivity.

Sediment Capping. Sediment capping is a remediation technique designed to isolate contaminants such as PCBs, PAHs, and heavy metals in terrestrial and aquatic sediments, preventing their migration into surrounding ecosystems. By preventing the migration of contaminants, sediment capping in this scenario minimizes pollutant exposure for terrestrial species like monarch butterflies and provides a safer environment for humans by limiting soil and water contamination. The approach supports cleaner, healthier habitats for wildlife and communities while addressing potential legacy pollution from industrial activities.

Electrokinetic Remediation. Electrokinetic remediation is applied to mobilize and extract heavy metals and organic contaminants such as PAHs and PCBs from polluted soils and groundwater. By applying low-voltage electrical fields, this technique induces electromigration, electroosmosis, and electrophoresis, which drive contaminants toward electrodes for collection and removal. This method not only removes contaminants from the soil but also addresses groundwater contamination, ensuring cleaner hydrological systems and improved habitat safety.

(Colacicco et al., 2010; Reddy et al., 2010).

This approach is particularly effective in areas where pollutants have seeped into both soil and subsurface water, making it a versatile solution for addressing contamination in complex environmental settings. However, site-specific optimization, including the use of biodegradable chelants and surfactants, is crucial for minimizing secondary environmental impacts and maximizing contaminant removal.

Phytoremediation. Phytoremediation is employed in areas with lower contamination concerns, where plants absorb, stabilize, and sometimes degrade pollutants such as heavy metals like zinc, lead, and cadmium. This technique is particularly valuable in addressing residual contamination, as it allows for recovering contaminated sites while integrating ecological and aesthetic functions. It is combined with continuous monitoring of plant bioaccumulation to track pollutant uptake and ensure safe ecosystem recovery.

Phytoremediation provides a cost-effective solution for managing minor contamination while supporting vegetation growth and ecosystem health. By combining this technique with continuous monitoring and design strategies incorporating public awareness and functionality, resilient landscapes that meet ecological and community needs can be created.

Phase 2: Secondary Remediation Strategies. The secondary remediation strategies for this alternative scenario build on initial efforts, moving from removing potential contamination to fostering long-term ecological recovery. The initial methods, including extract and haul, sediment capping, electrokinetic remediation, phytoremediation, and pollutant monitoring, target the likely main contamination issues. However, some residual contamination would be expected in certain areas, requiring further actions to stabilize pollutants, reduce environmental risks, and support habitat development.

There is no set timeline for secondary remediation measures; they will be implemented after evaluating the initial remediation phase. Once monitoring confirms that residual contaminants can be managed without extensive excavation or chemical treatment, soil stabilization and microbial bioremediation will be used. These methods will contain contaminants, prevent their spread into groundwater and surface water, and speed up natural degradation, allowing habitat restoration to proceed effectively.

Soil Stabilization. In former coal storage areas, soil stabilization techniques are employed to prevent contaminant leaching and enhance soil structure, creating a foundation suitable for plant establishment. Stabilizing agents, such as cement, bentonite, and organophilic clay, are used to immobilize pollutants like heavy metals and organic contaminants, ensuring that these compounds remain trapped within the soil matrix and are not bioavailable to plants and animals.

Research has shown that the addition of stabilizing agents like bentonite and organophilic clay significantly improves the immobilization of hazardous contaminants. For example, bentonite's high cation exchange capacity allows it to bind heavy metals effectively, while organophilic clay enhances the adsorption of organic pollutants, such as phenol, reducing their mobility by up to 81.8% (Heidarzadeh et al., 2021). This reduction in contaminant leaching minimizes ecological risks and creates safer habitats for species such as monarch butterflies and Eastern fox snakes.

Moreover, stabilizing agents contribute to the structural integrity of treated soils, which is critical for long-term remediation success. While higher clay content may slightly reduce compressive strength, including optimal ratios of cement and additives ensures the soil remains stable and suitable for vegetation growth and potential reuse. For example, studies demonstrated that soil treated with 30 wt% cement and 13.3 wt% organophilic clay achieved a compressive

strength of 3,839 kPa, making it safe for ecological restoration and infrastructure applications (Heidarzadeh et al., 2021).

Advanced stabilizing agents, such as hydrated calcium silicate and resin-based materials, have also been proven effective in low-temperature conditions. These compounds immobilize contaminants and maintain soil integrity, with compressive strength improving by 30.9% compared to untreated soil under cold conditions (Chen et al., 2024). Using stabilizing agents tailored to specific site conditions ensures effective pollutant containment while supporting vegetation growth and habitat creation.

By immobilizing pollutants and enhancing soil quality, soil stabilization creates safer habitats for terrestrial species and fosters the development of resilient ecosystems, addressing contamination sustainably.

Microbial Bioremediation. Microbial bioremediation is applied in areas with high PAH concentrations to break down complex hydrocarbons into less toxic substances. This technique leverages microorganisms' natural metabolic processes, including native and genetically modified strains, to degrade PAHs and other hydrocarbons (Caracciolo et al., 2020; Sadhana et al., 2021). By transforming harmful compounds into carbon dioxide, water, and simpler organic molecules, microbial bioremediation is critical for restoring soil and water quality, benefiting all six species by ensuring a safe and functional ecosystem.

Recent advancements in microbial engineering have enhanced the efficiency of PAH degradation, for example, genetically modified microorganisms (GEMs), such as *Mycobacterium* sp. PYR-1 and *Pseudomonas fluorescens* HK44, have been engineered to improve the breakdown of high molecular weight (HMW) PAHs, including pyrene and phenanthrene. These GEMs demonstrate increased enzymatic activity and environmental resilience, enabling faster

and more effective remediation in highly contaminated areas. Such strains also allow for monitoring of the remediation process, ensuring greater control and efficiency in ecological restoration (Sadhana et al., 2021).

In addition, microbial consortia enhanced by plant-root interactions have shown promise in contaminated sites. For example, poplar-assisted bioremediation fosters synergies between plant root systems and microbial communities, enhancing PCBs and PAHs' degradation while simultaneously stabilizing heavy metals. Root exudates support microbial populations capable of expressing genes related to hydrocarbon degradation and heavy metal resistance, creating a more robust remediation system (Caracciolo et al., 2020).

By integrating advanced microbial bioremediation techniques with habitat restoration, the site achieves a balanced approach to ecological remediation. This combined strategy addresses legacy contamination and fosters resilience and connectivity across diverse habitats.

Preventive Approaches. Preventive measures are crucial to reducing the likelihood of residual contaminant movement in soils, surface water, and groundwater after this proposed remediation plan for the alternative scenario. While initial and secondary techniques eliminate or stabilize pollutants, trace amounts of heavy metals and PAHs may remain, necessitating actions to stop their dispersion and secure long-term ecological health. Constructed wetlands, stormwater management systems, and riparian buffers serve as protective measures, filtering and stabilizing contaminants to protect restored habitats. Wetlands act as natural biofilters, stormwater systems manage runoff, and riparian buffers help minimize the transfer of pollutants into water bodies. Collectively, these strategies enhance remediation efforts, fostering sustainable ecosystems for essential species while preserving water quality and land stability.

Constructed Wetlands. Key areas are designated for wetland restoration to support

species such as the lake sturgeon, Blanding's turtle, and Eastern fox snake. Constructed wetlands are designed with fine substrates and strategic hydrological management to enhance water quality and biodiversity. These systems mimic natural wetlands by leveraging ecological processes such as sedimentation, microbial degradation, and nutrient uptake, which naturally filter pollutants and improve habitat connectivity between aquatic and terrestrial zones (Metcalf et al., 2018).

The extract-and-haul method is employed to remove contaminated sediments entirely, ensuring zero residual pollutants remain in the wetland substrates. This step provides a clean foundation for wetland restoration and eliminates potential sources of bioaccumulation in aquatic species, similar to methods used in large-scale sediment removal and restoration projects such as those described by Lortie et al. (1998). Post-removal, native plants are introduced to accelerate ecosystem recovery and stabilize sediment.

Constructed wetlands are multifunctional, providing additional ecosystem services such as flood control, carbon sequestration, and recreational opportunities. They integrate natural processes to address pollution abatement while promoting habitat restoration and species conservation. Hybrid designs, combining surface and subsurface flows, maximize pollutant removal efficiency by filtering suspended solids, facilitating microbial activity, and encouraging nutrient transformation within the wetland bed (Metcalf et al., 2018). Continuous monitoring ensures hydrological and ecological functionality, protecting sensitive species and maintaining water quality across the site.

Stormwater Management. Stormwater management systems are designed to reduce the contamination of runoff by heavy metals and PAHs while preventing the spread of contaminants to surrounding areas. These systems include integrated mechanisms for continuous monitoring of

contamination levels in both surface and groundwater to ensure effective mitigation. These systems protect the hydrological balance by capturing and filtering pollutants with vegetated buffers, constructing wetlands, and supporting nearby habitats.

Riparian Buffers. Riparian buffer zones along water bodies serve as critical tools to reduce soil erosion, filter pollutants, and prevent contaminants from entering aquatic habitats. These buffers, often composed of grasses, shrubs, and trees, enhance water quality by trapping sediment and contaminants, promoting infiltration, and stabilizing soils. For species such as the lake sturgeon, riparian buffers are essential for maintaining clean and connected environments, supporting habitat connectivity and water quality.

In the site context, the Slocum Canal connecting directly to the Detroit River complicates implementing riparian buffer zones. These artificial waterways are typically narrow and engineered, leaving limited space for natural vegetation buffers. Additionally, urbanization and industrial development in the area further constrain the available land, making large-scale riparian buffer zones impractical. Instead, more minor, strategically placed buffers could be designed to target key locations where runoff enters the canals or directly reaches the Detroit River, ensuring localized pollutant filtration and erosion control.

Research highlights the ability of even small-scale riparian buffers to trap sediment-bound nutrients like phosphorus and nitrogen, and improve biodiversity by creating corridors that connect fragmented habitats (Gordon et al., 2016). While large-scale buffers may not be feasible in this context, carefully designed interventions along critical points in the canal system could still contribute to maintaining water quality and protecting habitat connectivity for aquatic species like lake sturgeon. Habitat modeling for lake sturgeon in Pools 5A and 8 of the Mississippi River has emphasized the importance of stabilizing surrounding ecosystems and

protecting key habitat parameters, such as depth and substrate quality (Kelly, 2001).

By adapting riparian buffer designs to the unique constraints of the site, such as urban canals and limited land availability, the benefits of water quality improvement and ecosystem connectivity can still be achieved on a smaller scale.

With this complete description of the two scenarios, this report will move to the literature review section of the five variables that informed the design process and the assessment matrix of each variable used for evaluating the scenarios.

Carbon Sequestration

Burning fossil fuels such as coal has contributed to an increasing atmospheric concentration of carbon dioxide (CO₂) since the Industrial Revolution and the greenhouse effect on Earth (Mitchell, 1989). One strategy for mitigating CO₂'s warming effect is sequestering carbon from the atmosphere and storing it to prevent release (Lal, 2007). Carbon sequestration has two broad categories: abiotic sequestration, which does not require the intervention of living organisms and usually refers to injection into deep ocean, storage in geological layers, and mineral carbonation; biotic sequestration, which needs plants or microorganisms and often include photosynthesis, conversion of carbon to lignin, and soil carbon sequestration (Lal, 2007). Wetland, forest, and grassland all use biotic carbon sequestration. Since the project site has existing wetlands and vegetation, this section will consider the carbon sequestration potential of these three ecosystem types through a literature review and the associated assessment matrix.

Literature Review

This part will focus on mechanism and capacity for carbon sequestration by vegetation and different types of ecosystem, but it will begin with a note on the difference between carbon sequestration and storage.

Difference between carbon sequestration and carbon storage

These two are related concepts but differ from each other. Carbon sequestration refers to the process that plants take carbon dioxide from the atmosphere and convert it to glucose via photosynthesis, while carbon storage refers to the amount of carbon that an ecosystem such as wetland or forest holds (Agency of Natural Resources, 2024).

Carbon sequestration capacity of vegetation

The project site is bounded by W Jefferson Avenue and Van Horn Road to the west and Grosse Ile Parkway to the north, which are all busy roads with heavy traffic. In order to make the carbon sequestration capacity values more relevant, this review intentionally selected a study of vegetation near an expressway.

There were three categories of vegetation near the expressway: trees, shrubs, and herbs. The method of calculating the carbon sequestration capacity was specific to the vegetation category: herbs used the biomass method that had a harvest, desiccation, and weight conversion process; trees and shrubs used the assimilation method that multiplied the per unit area net assimilation with total leaf area (Fu et al., 2019). Results found that herbs' carbon sequestration capacity was negligible (0.17%), and trees (74.87%) sequestered much more than shrubs (24.96%).

As shown in Table 3 below, the top three tree species based on the annual total kilogram sequestered carbon were Camphor tree (*Cinnamomum camphora*), Golden rain tree (*Koelreuteria paniculata*), and Chinese photinia (*Photinia serrulata*). The top three shrub species based on the annual kilogram sequestered carbon were Oleander (*Nerium indicum*), False indigo bush (*Amorpha fruticosa*), and Japanese aralia (*Fatsia japonica*). However, when considering the average carbon sequestration per plant, the top three tree species were Golden rain tree

(*Koelreuteria paniculata*) at 2348 kg/m², Ginkgo (*Ginkgo biloba*) at 2338 kg/m², and Camphor tree (*Cinnamomum camphora*) at 2129 kg/m²; the top three shrub species were Oleander (*Nerium indicum*) at 213 kg/m², Japanese camellia (*Camellia japonica*) at 108 kg/m², and Weeping forsythia (*Forsythia suspensa*) at 104 kg/m² (Fu et al., 2019).

Vegetation category and ranking	Annual total kilogram sequestered carbon	Average carbon sequestration per plant
Tree NO. 1	Camphor tree	Golden rain tree
Tree NO. 2	Golden rain tree	Ginkgo
Tree NO. 3	Chinese photinia	Camphor tree
Shrub NO. 1	Oleander	Oleander
Shrub NO. 2	False indigo bush	Japanese camellia
Shrub NO. 3	Japanese aralia	Weeping forsythia

Table 4: Trees and shrubs with the top 3 highest carbon sequestration capacities based on 2 calculation methods.

Carbon storage capacity of wetland and forest

Wetlands and forests use different mechanisms for carbon sequestration. The anoxic soil of wetlands has a slow decomposition rate and is favorable to organic substance accumulation, so wetlands are important carbon sinks (Nahlik & Fennessy, 2016). Wetland plants often have higher gross primary productivity rates, so they assimilate more atmospheric carbon during photosynthesis and store it in leaves and roots. Wetlands also have a bacteria mediated biochemical process for carbon. Water table height and temperature can affect a wetland's

carbon sequestration potential because these two factors determine bacteria's decomposition rate of organic matter (Were et al., 2019).

Without human disturbances of vegetation, soil, and hydrological regimes, wetlands can store carbon for hundreds of years (Were et al., 2019). Michigan wetlands' average carbon storage capacity is around 478 tC/ha, but this number is decreasing due to anthropogenic land use changes (Nahlik & Fennessy, 2016). Protection, restoration, and construction are primary approaches for enhancing carbon sequestration and storage in wetlands. Protected wetlands store 15-50% more carbon than disturbed ones, and restoring 230 million ha of wetlands in the world can sequester 4 MtC/year (Were et al., 2019). If both protection and restoration are not feasible, creating/constructing wetlands can also help sequester and store carbon. A constructed wetland's carbon sequestration rate can climb to 219-267 g C/m²/year after 15 years. However, constructed wetlands are traditionally designed for wastewater treatment and have a sequestration potential of 484 to 649 kg C/year (Were et al., 2019).

Besides these three non-manipulative approaches, directly suppressing the organic matter decomposition rate is another way to increase a wetland's carbon storage capacity. Possible strategies include using biotechnology to manipulate microbes and vegetation in wetlands; adding biochar to reduce methane (CH₄) emissions; fertilizing wetland soil with elements such as phosphorus, nitrogen, and sulfur; and adding humic acid to soil to increase carbon's residence time (Were et al., 2019). These manipulative strategies are still new and need careful evaluation of wetland conditions before application (Were et al., 2019).

Forests store carbon via vegetation, soil, and litter, and there are specific methods for estimating each of the three sinks' carbon storage capacity (Sun & Liu, 2019). Vegetation carbon can be estimated by regional forest inventory data (average biomass, biomass regression,

volume, and conversion factor), satellite based techniques (remote sensing, synthetic aperture radar, and LiDAR), and process modeling (geostatistical and mechanism); soil carbon can be estimated by soil type sampling, life belt, empirical modeling, and decomposition rate calculation; and litter carbon can be estimated by aboveground biomass and carbon turnover rate, though litter only stores 5% of carbon in forests (Sun & Liu, 2019).

Vegetation, soil, and litter store carbon in forests at 43.1, 132.7, and 6.68 Mg/ha respectively based on studies in Asia (Sun & Liu, 2019). A study conducted at the University of Michigan Biological Station focused on a specific type of forest, mixed-deciduous forest dominated by aspens, and found that the average carbon storage rate was 1.53 Mg/ha/year (Gough et al., 2008).

Carbon storage capacity of grassland

Michigan has five types of grassland: hillside prairie on slopes; dry sand prairie on glacial outwash plains; dry-mesic prairie near railroads and agricultural fields; mesic prairie around cemeteries, railroads, and agricultural fields; and mesic sand prairie in depressions of glacial outwash plains (Michigan United Conservation Clubs, 2022). Typical vegetation of Michigan grassland ecosystems differs by temperature: in warm season, Indiangrass, big bluestem, little bluestem, switchgrass, and prairie cordgrass are more common; in cold season, Canada wildrye, redtop, and June grass are more prevalent (Michigan Department of Natural Resources, 1999). At the project site near Detroit River, typical vegetation includes blue-joint grass, shoreline sedge, rose mallow, and swamp milkweed (U.S. Fish & Wildlife Service, 2024).

Over 90% of carbon stored in grassland ecosystems is below the ground as soil organic carbon (SOC), but SOC is highly vulnerable to land use conversion, overgrazing, and climate change (Bai & Cotrufo, 2022). SOC is mainly particulate organic matter and mineral-associated

organic matter (MAOM). Due to its longer soil residence time, MAOM is responsible for long term carbon storage. Improving plant diversity and microorganism (such as arbuscular mycorrhizal fungi) abundance contributes to SOC accumulation and stabilization, and restoration and management efforts can further increase grassland's carbon storage potential (Bai & Cotrufo, 2022).

There is limited literature on the carbon storage potential of individual vegetation, so this review will instead focus on the storage potential of the grassland ecosystem. Estimated carbon storage values usually vary significantly among studies due to the use of different methods. For example, remote sensing is not an appropriate method for estimating grassland SOC (Ma et al., 2016). By integrating field-measured carbon data via six methods across ten years, a meta-analysis found that grassland SOC density had a range of 1.892-24.856 kgC / m² and a mean of 8.16 kgC / m² (Ma et al., 2016). A more recent study used the model tree ensemble model and got the results of an 8.82 kgC / m² SOC density. The study also found that restoration efforts such as limiting grazing and minimizing disturbance could increase carbon storage by 47-71% (Song et al., 2018).

Carbon storage capacity in Michigan

Carbon sequestration values differ by ecosystem types. Based on the literature review above, an average Michigan wetland sequesters 478 tC/ha. Forest stores 43.1, 132.7, and 6.68 MgC/ha via vegetation, soil, and litter. Grassland stores 8.16 kgC / m² on average as soil organic carbon (SOC). Multiplying the per area sequestered carbon by the amount of wetland, forest, and grassland area will get the value for carbon sequestration capacity.

Assessment Matrix

After discussing carbon related literature review, this part will discuss how to assess carbon sequestration in both the control and alternative scenario. In order to accommodate the integrated assessment among all variables, carbon sequestration conditions are transformed into numbers from 0 to 3. The scenario receives 0 if any type of ecosystem is missing. For example, the control scenario does not have forests, so it receives 0 for “forest”. When a type of ecosystem is present in both scenarios, the one with a higher carbon sequestration value receives 3 while the other receives 2.

Energy Generation and Storage

A transition away from fossil fuels and towards renewable energy has begun unfolding in recent years. When considering the creation of new generating sources, a key issue will be where these are located. Former industrial sites, such as the project site, offer land that is not currently in use and may have less tradeoffs for use than other sites (Schutt, 2024). Considering what energy generation or storage potential may exist at the project site can help to show what could be done without modifying existing land uses.

Based on studies of similar sites, the project site could be contaminated and thus would likely need groundwater treatment. Using energy generated on-site to power treatment equipment could be preferable to connecting to off-site municipal electricity grids. A review of the latest technology showed that solar panel generated electricity was powerful enough for operating water treatment equipment (Maktabifard et al., 2018).

In doing so, the site could be self-sufficient and use a cleaner mix of electricity than what is typically offered in municipal grids in Michigan. Siting renewable energy generation on the site, which was formerly used for energy generation, could show how steps to limit climate

change, like transitioning away from fossil fuels, can be less drastic in reality than they may be imagined to be. For this project, solar, biomass, and hydroelectric generation were considered, but only solar and hydroelectric were found to be reasonable for the project site. Information on biomass can be found in Appendix C. This section considers the energy generation capacity from solar panels, the energy storage potential in batteries, and the applicability of using energy generated on-site to power groundwater treatment equipment.

Literature Review

Solar

Solar resources are infinite and solar-based energy generation produces minimal to no greenhouse gas emissions, so many cities around the world have integrated this renewable energy into their planning to reduce the carbon footprint of urban areas (Akrofi & Okitasari, 2022; Hayat et al., 2018). Current technologies enable conversion of solar energy into electricity via photovoltaic cells (PV cell) or concentrated solar power (CSP), so cities can use the generated electricity to power public facilities such as street lighting (Hayat et al., 2018). At the utility scale in 2023, only 3.9% of total generated electricity in the U.S. was from solar power, so there is room and good potential for improving the share of solar generated electricity in the future (U.S. Energy Information Administration, 2024).

The CSP method uses steam from solar irradiation to generate electricity and requires complex power systems during production (Hayat et al., 2018). The project site is unable to support the CSP method, so this review will focus on the PV cell method. There are three generations of PV cells: the first generation is made of monocrystalline or polycrystalline silicon and has the largest share in the PV cell market; the second generation needs less silicon because it uses the thin-film cell; and the third generation achieves a huge cost reduction compared to the

second generation because the third generation uses quantum wells and dots to improve solar irradiation absorption (Hayat et al., 2018). Greater detail, including advantages and disadvantages of each PV cell generation, are in Table 5.

PV cell generation	Advantages	Disadvantages
First	-Highest market share -Efficient at lower temperatures	-Higher production cost -Worse efficiency at higher temperatures
Second	Lower production cost due to less silicon material	-Smaller market share -Need rare elements such as tellurium
Third	Lowest production cost	Lower efficiency

Table 5: Detailed advantages and disadvantages of each PV cell generation.

Studies show that using PV cells to power urban street lighting via solar energy has good economic and sustainable feasibility. A study chose a 2-lane 10 km highway with light poles 30 m apart from each other and conducted an economic assessment of a PV cell powered light emitting diode (LED) lighting system (Wu et al., 2009). Even though the solar powered LED lighting system has a higher installation cost, the payback time was only 3.3 years. In addition, the system's lifetime exceeded 10 years and LED lamps could save energy by 75% compared to conventional mercury lamps for street lighting systems (Wu et al., 2009).

Besides economic feasibility, PV cells also have good sustainable feasibility. A study used computer simulation models to evaluate the performance of different PV cell configurations designed to power an urban street lighting system. The islanded PV configuration is simpler and has a larger battery than the grid-connected configuration, and typically a street light pole carries two 80 W PV panels (Liu, 2014). Results showed that there was an inverse relationship between PV cell system cost and local solar irradiation and an inverse relationship between solar

irradiation and CO₂ emission from PV cell systems (Liu, 2014). These understandings of feasibility are important to keep in mind when considering lighting possibilities for an alternative scenario, and the viability of solar generation systems.

For this project, a key question for solar energy generation is how much electricity could be generated at the project site. This can be calculated as shown below in (1) (Diantari & Pujotomo, 2016).

$$\text{Power Generation Capacity} = A * \text{Solar Insolation} * \eta_{PV} \quad (1)$$

The project site area is 8,928,727.73 ft², or 829,499.046 m². The insolation for Trenton, MI is 4.69 kWh/m²/day, or 0.195416666666 kW/m² when multiplying by a conversion factor of 1 day/24 hours (*Solar Energy and Solar Power in Trenton, MI*, n.d.). Assuming a monocrystalline panel efficiency, as it has the highest energy efficiency and would align best with the goal of energy generation, the panel efficiency would be 24.4% (Dhilipan et al., 2022). With these values, using equation (1), power generation capacity can be calculated to be 39,551.90 kW, or 39.55 MW, if the entire site was covered with monocrystalline solar panels.

For comparison, the TCPP had a nameplate capacity of 775.5 MW (U.S. Energy Information Administration, 2023). Even if the full area of the site was used for solar generation, there would be a sharp decrease in generation capacity. Given that the TCPP has already been decommissioned, generation at this site does not necessarily need to meet the former capacity of the plant. Any reliance on electricity generated from the plant has likely already been substituted for other generation sources. Any renewable capacity installed at the project site, like solar, could serve as a way to meet demand with less fossil fuel use, either by decreasing production or decommissioning existing fossil fuel plants.

Solar panels can be implemented in multi-use settings, such as above parking lots or on building roofs. When placed above parking lots, they are able to reduce the urban heat island effect, shade the cars and lot below them, and generate renewable energy (Pantić et al., 2020). When considering possible access points for human communities, a parking lot is a likely choice given the infrastructure surrounding the project site. Placing solar panels in a solar canopy above any such lot can then mitigate the increased urban heat island effect from increased asphalt and contribute to the total renewable energy generation of the site. Rooftop solar panels can further increase generation when considering any buildings in the design. By using solar panels to create multi-use spaces, multiple benefits can be seen, and the total productivity of the project site for energy generation can increase.

Hydropower

Hydropower refers to electricity generated from the energy of flowing water, and the water can be natural flow, like waterfalls, or human related flow, like municipal water supply pipes (Bagher et al., 2015). The moving water pushes the blades of a hydraulic turbine to turn and this process generates electricity (Bagher et al., 2015). The generation potential usually depends on the dropping distance and amount of flowing water (Bagher et al., 2015). At the utility scale in 2023, 5.7% of total generated electricity in the U.S. was from hydropower (U.S. Energy Information Administration, 2024). The water cycle driven by the sun provides the input, so hydropower is a renewable source of electricity (U.S. Department of Energy, 2023).

Generating hydropower usually needs a carefully designed dam or industrial hydroelectric power plant, but those two are not feasible options for the project site (Bagher et al., 2015). However, recent studies have shown the potential of a new approach to hydropower: installing micro hydraulic turbines on municipal water supply pipes and generating electricity to

power urban facilities such as street lighting.

An experimental study evaluated the novel micro hydraulic turbines (also called Pump as Turbines) that were installed on drinking water distribution networks because of their low installation costs and feasibility for deployment in municipal areas (Ocana-Miguel et al., 2022). The turbines reached the optimal operation capacity when water flowed at 13.5 L/second, generated 1.6 KW of electricity, and were designed to power 10 nearby LED lights of 40 W each (Ocana-Miguel et al., 2022). Results showed that the micro turbines could generate 11.2 KWh of electricity per day, had a hydraulic efficiency of 70% and electric efficiency of 85%, and were able to power a street lighting system of 770 W at maximum. With a payback time of only 3.79 years, the novel micro hydraulic turbines showed great potential for powering municipal lighting systems (Ocana-Miguel et al., 2022). A more recent study built on the idea and expanded it to the scale of a mini hydropower plant that was capable of producing 632 MWh per year and supporting the street lighting needs of a 35,000-citizen city (Pachamanov et al., 2024). This technology offers a novel way to generate electricity within some of the constraints present at the project site, and a possibility to integrate with planned design features for an alternative scenario.

When considering hydropower for this project, installing hydraulic turbines will focus on existing buildings because they likely have existing pipes for water supply and distribution. If information on the TCPP site's water distribution pipe system is available, recommending specific installation locations of turbines will be possible.

Energy Storage

Use of an energy storage system has the potential to increase long-term sustainability at the local level and larger scales. There are a variety of possible methods of storing energy, but all are able to achieve this goal. Energy storage systems can reduce energy use, if the energy is

stored during off-peak times and used during on-peak times (Elalfy et al., 2024). They can reduce carbon emissions, if their use supports renewable energy sources instead of fossil fuel sources (Elalfy et al., 2024). Finally, as some renewable energy methods like wind or solar are intermittent, energy storage can reduce the impact of intermittency and, depending on location, can support remote individuals (Elalfy et al., 2024). Given the location of the project site, there is less potential for supporting remote individuals who are not connected to an existing grid. However, the opportunity does exist here with energy storage to support more renewable energy sources and increase resiliency in case of an outage occurring.

More specific technologies that could be considered vary based on the site design. If solar or wind energy is on-site, storage systems like flywheels can be recommended due to their fast response (Elalfy et al., 2024). The response time for lithium-ion batteries is comparable to flywheel response time, and so battery storage would be another viable option to combine with on-site renewable energy generation (Koltermann et al., 2023). When designing an alternative scenario, these technologies offer ways for battery storage to be included and different tradeoffs with other possible land uses.

DTE has announced that there will be a battery energy storage facility on part of the former TCPP, with a storage capacity of 880 MWh per cycle (Owings, 2024). With that in mind, and the space available on the site, it is reasonable to assume that battery storage would be the most conducive energy storage method for the project site. The current plan by DTE for battery storage will support the same amount of energy that the TCPP did, as the transmission system in the area can feasibly support that much energy (Thompson, 2024). Any additional batteries would expand the storage capacity, potentially enabling more renewable energy elsewhere in the transmission network, but may lead to a need for transmission upgrades for additional capacity.

An additional benefit with siting energy storage on this site is the decreased demand for it to be sited elsewhere. If considering a contaminated site, like a brownfield, a storage system could use that space, minimizing the need for other, more valuable land (Schutt, 2024). Of course, doing so takes away from other possible uses. If batteries are located in part of the site design, this minimizes the possible human uses or habitat creation of that portion of the site. The long-term and larger scale benefits for sustainability are present, due to potential emissions reductions, but the reduction of smaller-scale environmental benefits for habitat may mean the tradeoffs for larger storage arrays are not worth it when considering all possible site uses.

The ultimate use and sizing of any battery storage on the site would be dependent on intended use for the stored energy, especially if it is not used for any electricity needs on-site. If done by a regional distribution power system operator, it could act as a way to ensure technical improvements (Yang et al., 2024). Doing so could mean that excess renewable energy is stored and deployed when needed, which would improve the load profile, maintain voltage quality, or allow for the delay of upgrading of facilities due to the increased capacity that storage offers (Yang et al., 2024). If storage is controlled by residents, it could act as a way to lower bills, by storing energy when costs are low and using it when costs are high (Yang et al., 2024).

Additionally, batteries could act as a source of emergency power and help mitigate any potential outage issues for the community surrounding the project site.

Assessment Matrix

Assessing the alternative scenario with respect to energy involves two major aspects, generation and storage. The first step in assessing is determining if either of these are present in the alternative. If they are not, then nothing further is needed. If they are, then more specific assessment can occur.

For generation, this means determining how much of the total possible energy generation is actually designated on the site. The calculation for theoretical solar generation, discussed above in equation (1), can be applied to the total area designated for solar panels in a given design. Calculating the energy generated by hydraulic turbines requires the velocity of water flow, but it is impossible to get this information about the TCPP site since there is no available knowledge of the site's water distribution system. However, past studies have shown that turbines can generate 11.2 KWh of electricity per day at the optimal water flow rate of 13.5 L/second, enough to power 10 nearby LED lights of 40 W each. The assessment matrix of hydropower can be categorical: is the design scenario able to meet the 11.2 KWh per day amount?

For storage, what is suitable can depend on the ultimate use of the stored energy and the energy needs on-site. If there is grid connection, then storage can be as small or large as desired by spacing, so its presence (or lack thereof) would be the full assessment. If there is not a grid connection, then the storage would need to have a capacity that could power the site needs for the longest period of time there may not be energy generation. For solar, this would mean at least overnight, or a longer time scale given the weather patterns in Michigan.

To compare with other matrices for the integrated assessment, the following scale was used. There are three indicators, but the parameter for solar is quantitative while the other two are qualitative, making this slightly different than the other variable matrix scales. First, the qualitative parameters of hydropower and energy storage are assessed. Meeting none of these is a one, meeting one of these is a two, and meeting both would be a three. Then, the quantitative value for solar is considered. If the two scenarios have the same score, the one with the larger value for solar will move up the overall scale, while the other will retain the same score.

Habitat Quality and Connectivity

Literature Review

Biodiversity Assessment

Sustainable remediation technologies, such as sustainable immobilization, low-impact bioremediation, in-situ chemical treatment, and passive barriers, are essential to reduce the environmental footprint and maximize net benefits in remediated sites. In brownfield sites, biodiversity losses can occur if remediation is not conducted with sustainability in mind (Hou et al., 2023). The significance of biodiversity in brownfield development and remediation has been highlighted in several research papers, notably by Harrison and Davies (2002), in which they argued how brownfield sites in London have been recognized for their potential to host diverse wildlife. Brownfield sites can serve as important urban habitats, providing opportunities for rare and valued species to thrive. According to Harrison and Davies (2002), there is a growing number of conservation professionals in public, private, and voluntary sectors who are actively involved in negotiating biodiversity protection within the redevelopment process. Their strategies range from using scientific evidence to engage developers to advocating for more inclusive approaches that involve local communities.

Many studies argue the need for a more proactive approach to biodiversity conservation in urban redevelopment, suggesting that integrating ecological considerations into planning policies and practices can help ensure that the biodiversity value of brownfield sites is not overlooked, and may even be prioritized. The planning system currently often prioritizes economic and social sustainability over environmental sustainability. This is due to the tension between the pressures to develop brownfield sites for economic and urban regeneration purposes and the need to preserve their biodiversity value, which is shaped by political, economic, and

social factors that influence decision-making at different levels (Evans, 2002). Furthermore, the complexity of balancing biodiversity conservation with development goals means that ecological assessments can sometimes become a "tick box exercise," leading to insufficient consideration of biodiversity value (Cox & Rodway-Dyer, 2003). To mitigate this, raising awareness about the value of urban green spaces, interdisciplinary collaboration, and ensuring compliance with environmental policies will help enhance biodiversity conservation efforts in brownfield redevelopment.

Lack of proper methods to assess biodiversity on brownfield sites would make it difficult to ensure that their ecological value is properly considered in planning and redevelopment processes (Hunter, 2014). One method that may be used for biodiversity assessment is Cost-Surface Modelling (CSM), as mentioned in Laforzezza's (2008) piece on ecological assessments for designed alternative brownfield rehabilitations. CSM, in the case of biodiversity assessment within brownfields, is used to map species dispersal and habitat connectivity. Larger and more connected vegetation patches (as modeled in the CSM) support greater species dispersal, indicating higher biodiversity potential. This measure of habitat connectivity is critical for evaluating the success of brownfield rehabilitation in terms of biodiversity recovery (Shippers et al., 1996). Connectivity between habitat patches is crucial for supporting populations and facilitating recolonization, which is key to long-term biodiversity (Opdam & Steingröver, 2008).

Habitat Connectivity

Connectivity has received increasing attention as one of the key factors to restore habitat sites, protect biodiversity, and facilitate the habitat adaptation ability of climate change. Landscape connectivity is the degree to which the landscape facilitates or impedes movement among resource patches. It is often referred to as the functional connectivity of landscapes and

distinguished from the structural connectivity, which refers to the spatial contiguity or proximity of related landscape elements (Be'lisle, 2005). Habitat connectivity is the ability of organisms and/or their genetic material to move among their populations and potential habitats, coined by Merriam (1984). Habitat connectivity is most associated with biodiversity and the integrity of natural populations (Butler et al., 2022). However, with the acceleration of urbanization, habitat became fragmented, which has an adverse impact on the individual movement in ecosystems. This also impedes the gene flow and can lead to gene isolation, resulting in species extinction. Analyzing connectivity can also help researchers to estimate the ecosystem structure change and species diversity over the next few years. The importance of connectivity in conservation and reserve design has fostered a proliferation of connectivity metrics (Wang, X et al., 2014).

Opdam and Steingrover (2008) discussed the importance of connectivity between terrestrial habitats, and how ecosystem patches should be connected in a network to allow species movement and interactions. Connectivity between habitat patches is crucial for supporting populations and facilitating recolonization, which is key to long-term biodiversity. Maintaining spatial cohesion between ecosystem patches is also essential, which involves ensuring habitat quality, network density, and matrix permeability. In addition, larger and more connected vegetation patches support greater species dispersal, indicating higher biodiversity potential. This measure of habitat connectivity is critical for evaluating the success of brownfield rehabilitation in terms of biodiversity recovery (Laforteza et al., 2008).

There are three widely-used approaches to quantifying habitat connectivity. The first and the most common is least-cost analysis, which identifies the least cost route for species to migrate from one area to another. It is a measure for distance modified with the cost to move between habitat patches, based on detailed geographical information of the landscape as well as

behavioral aspects of the organisms studied (Adriaensen et al., 2003). The second is circuit theory, which treats the routes between different habitat patches as an electrical circuit. Here, the elements of species are moveable, and can analyze multiple movement pathways at the same time. The result shows well-connected habitat patches have continuous habitat between them, while poorly-connected habitat patches have constraints between them (Deborah et al., 2012). The last one is Graph theory, which combines the least-cost analysis with circuit theory, treating the network of habitat systems as the combination of nodes and edges. It can analyze the contributions of multiple least-cost pathways for the configuration of the overall habitat network (Deborah et al., 2012). General guidance suggests two steps to integer the connectivity as one metric on site restoration process. First, establish the priority of restoration. If the main objective of restoration is to conserve biodiversity, actions to improve habitat connectivity take priority. Then, consider the position of the habitat restoration sites. The optimal habitat restoration sites should have highly connected habitat patches, and facilitate biological fluxes in existing routes, and the non-habitat area could create new routes among patches (Tambosi et al., 2013).

Quality of Terrestrial Habitat

Terrestrial habitat design must also be specified for the fauna in question. According to Adamus (2007), the quality of habitat for many wetland-dependent species is tied to specific attributes of wetland vegetation, such as the presence of submerged aquatic vegetation, emergent marshes, and the overall persistence of surface water. In the wider Michigan region, high-quality habitats are determined by a combination of vegetation structure, water availability, and connectivity to larger, undisturbed areas, providing a balance between wetland and upland resources that support biodiversity.

For certain species, vegetation also plays a key role in establishing a good habitat. Accessibility to food sources and minimum environmental stressors are also important, tying back to the importance of proper vegetation.

Overall, the most important factors in determining habitat quality, especially in restoration sites, is patch size and connectivity with other habitats. Fragmented habitats that limit species movement are considered inadequate habitat designs. Having high matrix permeability, related to species movement limitations, is also important. The existence of man-made infrastructures, such as roads and pathways, might hinder this. This also relates to disturbance levels such as noise and human movement. Therefore, incorporating corridors or permeable areas will help increase and preserve biodiversity.

Wetland Restoration

As discussed in the site analysis section, the Detroit River system has lost much of its wetlands, with some initiatives occurring to promote ecological recovery and sustainability in impaired areas (Hartig & Bennion, 2017). One of the primary objectives of wetland restoration is to safeguard biodiversity and promote species conservation. Wetlands are crucial habitats for numerous species, including lake whitefish, mudpuppies, and the endangered salamander mussel. Historically, the wetlands of the Detroit River offered abundant spawning sites for lake whitefish; however, urban and industrial development has led to severe habitat degradation (Roseman et al., 2007). The loss of these habitats has far-reaching consequences, as wetlands create the necessary conditions for species to complete vital life stages, such as spawning and larval development. Likewise, mudpuppies depend on wetland habitats for survival and serve as indicators of environmental health. They also act as host species for the salamander mussel, highlighting the interconnected nature of wetland inhabitants (Stapleton et al., 2018). Wetland

restoration allows these species to flourish, reversing biodiversity declines and contributing to a balanced regional ecosystem.

In addition to supporting biodiversity, wetland restoration increases habitat complexity, which is essential for sustaining the life cycles of aquatic and amphibious species. Elements such as submerged rocks, woody debris, and vegetative buffers create a range of microhabitats for species like lake whitefish and mudpuppies, providing spawning sites, foraging regions, and shelter (Roseman et al., 2007; Stapleton et al., 2018). These intricate habitats not only enhance ecosystem resilience but also facilitate the coexistence of various species. Restoration initiatives in the Detroit River and Lake St. Clair illustrate how structural diversity promotes species recolonization and boosts ecosystem health (Hartig & Bennion, 2017). Furthermore, by supporting multiple species at once, habitat complexity enhances the overall advantages of wetland restoration. Well-planned restoration projects ensure that these ecosystems remain viable, self-sustaining, and ecologically rich over time.

Wetlands also play a vital role in enhancing water quality through natural processes like sedimentation, nutrient transformation, and microbial uptake. These processes allow wetlands to function as efficient natural filters, trapping pollutants such as nitrogen, phosphorus, and suspended sediments that often stem from agricultural and urban runoff (Knox et al., 2008). For example, natural wetlands in agricultural areas can decrease nitrate loads by as much as 94% and retain between 33 and 56% of total nitrogen, significantly lowering nutrient pollution downstream (Knox et al., 2008). Similarly, constructed wetlands have proven to be very effective in urban environments, achieving phosphorus removal and other pollutants with retention rates of up to 71% during high-flow events (Wahlroos et al., 2015). By reestablishing vegetation and improving wetland structures, restoration initiatives stabilize sediments and help

reduce the effects of algal blooms often triggered by excess nutrients like phosphorus (Irwin et al., 2018).

The advantages of enhanced water quality extend well beyond mere pollution management. Improved water clarity and decreased pollutant loads foster aquatic biodiversity, support recreational activities, and ensure safer drinking water sources for nearby communities. These insights emphasize the diverse value of wetland restoration and highlight its significance in developing resilient ecosystems that promote ecological and human welfare. Incorporating water quality improvement into wetland restoration contributes to the long-term sustainability of these essential habitats and their services to the environment.

Assessment Matrix

The following assessment matrix was developed based on the literature review conducted that focused on the Detroit River ecosystem and the best ways to consider habitat. Focus is given to the six species of interest with the different identified indicators.

Habitat Connectivity and Fragmentation

The evaluation for habitat connectivity for this project follows the guidance of connectivity metrics for conservation and monitoring to assess multi-species landscape connectivity (Keeley et al., 2021). Specifically, key species approaches are used to generate potential assessment matrices. The landscape connectivity analysis is divided into two levels. One is functional connectivity assessment, which measures and reflects each species' movement ability and the level of risk encountered when traveling in surrounding features. Another is structure connectivity assessment, which can be measured using global map layers, and mainly includes a matrix of distance of the project site to its nearest neighbor, and potential habitat within the buffer. Here, the buffer definition depends on the home range of each species, and the

buffer area is the area with site location as the center and home range as the radius.

Figure 24 illustrates the distributions and habitat locations of the six key species (lake sturgeon, Eastern fox snake, Blanding’s turtle, Canvasback duck, monarch butterfly, and bald eagle). It serves as a visual aid to inform habitat connectivity evaluation methods, by highlighting migration routes and spatial proximity to adjacent habitat patches.

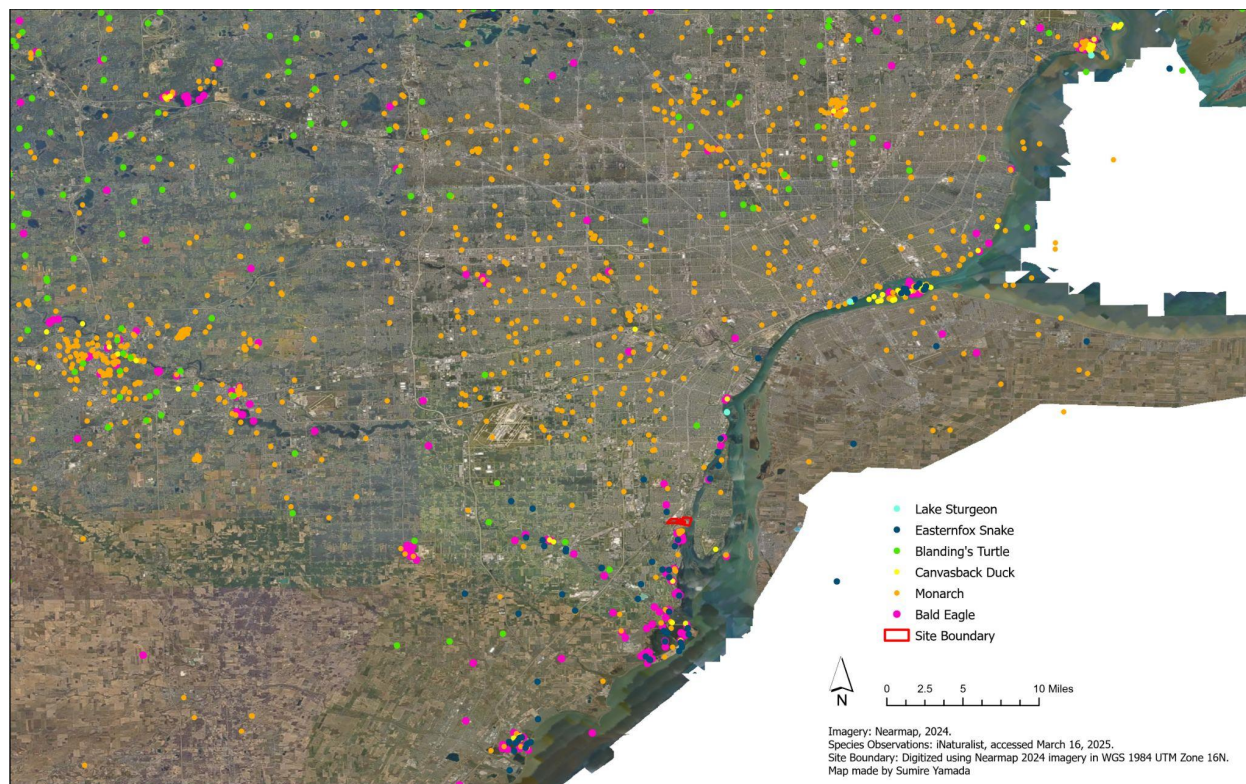


Figure 24: The observations and habitat locations of the six key species (lake sturgeon, Eastern fox snake, Blanding’s turtle, Canvasback duck, monarch butterfly, and bald eagle) near the project site.

The habitat connectivity assessment framework for the bald eagle is shown in Table 6 to provide insight into what this framework looks like, and the frameworks for the remaining species are in Appendix D.

Parameters	Good Condition	Medium Condition	Poor Condition
Functional Connectivity			
Migration path integrity	The patch decreases matrix resistance between surrounding habitats.	The patch reduces matrix resistance, but movement is still partially restricted.	The patch does not decrease matrix resistance, resulting in high habitat fragmentation.
Potential physical boundaries	The physical boundaries (e.g. roads, streets) are less impermeable for bald eagles.	Some (1-2) human activities are partially disturbed bald eagles .	Heavy (>3) commercial activities and human disturbances.
Structural Connectivity			
Distance to Nearest Patch	Distance to nearest patch < 10km	Distance to nearest patch between 10 km to 15 km	Distance to nearest patch > 15 km
Habitat Area Within Buffer	>70% of the habitats on the main migration routes are suitable	40-70% of the habitats on the main migration routes are suitable	<40% of the habitats on the main migration routes are suitable

Table 6: The bald eagle's habitat connectivity assessment framework

Habitat Size and Quality

The recovery of endangered wildlife populations is dependent on understanding the habitat requirements that are necessary for supporting said species, mainly in reproduction and survival (Garrett et al., 1993). Habitat patch size and quality are important variables used to assess the overall quality of the designed habitat, particularly when designing conservation-purposed habitats. Habitat quality can be defined as the resources and conditions in an area that produces occupancy (Hall et al., 1997). Habitat quality plays a role in the distribution patterns of species since survival, fecundity, and density are key drivers for the survival of a population in

fragmented as well as in continuous landscapes (Mortelliti et al., 2010). Meanwhile, habitat patch size, in various literature, can be seen as having a linear relationship with patch quality; namely, higher patch quality is quantified by increasing patch size and decreasing patch isolation (Hanski, 1998). Although, some also believe that smaller patches with the same values of population parameters as a larger one will result in a patch of higher quality, indicating a negative dependence between patch area and patch quality (Van Horne, 1983).

Some techniques exist to assess habitat quality based on Mortelliti et al. (2010), such as the direct measurements of the habitat's attributes. This ranges from vegetation structure to depth of ponds, depending on the target species (Denoel & Lehmann, 2006). Some cases even mentioned the habitat or patch size itself as a measurement of habitat quality (Anzures-Dadda & Manson, 2007). Another common measure of habitat quality is through the availability of resources, such as plant density for certain invertebrates to nesting area availability and food abundance for more complex species.

Unfortunately, Mortelliti et al. (2010) suggests that there is no standard definition or measurement of patch quality in fragmented landscapes. Despite the majority of studies using patch internal structure (or vegetation structure) as a surrogate measurement for the quality of patches, a general consensus on how to measure such variables is still lacking (Lindenmeyer et al., 2008). Due to how many of these variables are inherently species-dependent, the terms patch structure and patch quality should not be used interchangeably unless there is a clear biologically meaningful link between them. Failing to acknowledge this will lead to a simplistic or even spurious interpretation of results (Mortelliti et al., 2010).

For this project, the context of habitat connectivity and habitat size and quality is separated and analyzed as two separate variables. Mortelliti et al. (2010) emphasized how

conservation efforts should focus not only on patch connectivity, but also on maintaining and improving habitat quality. Specifically, connectivity may be important for species movement and genetic diversity, but it does not guarantee species persistence. Habitat quality determines whether species can establish and thrive, however isolated high-quality patches may not sustain populations in the long term. Furthermore, some studies also suggest that patch size and isolation are poor predictors of species occupancy (Prugh et al., 2008). Therefore, biodiversity conservation must consider the whole landscape, including the matrix, not just isolated habitat patches, despite the importance of patch sizes. Instead of merely making the patches larger, one must also improve the habitat quality of the surrounding matrix for better conservation outcomes (Lindenmeyer & Franklin, 2009).

Due to a lack of standardized methods in assessing habitat quality, the species approach is used here to assess habitat size and quality for each species of interest in this project. The parameter for each species' habitat differs depending on the needs that are mentioned in different studies (e.g., water depth, tree availability, proximity to urbanization, etc.). The key habitat composition requirements for six different species, as discussed earlier, were compiled into a matrix that outlines their habitat needs in terms of both size and quality. Based on this matrix, habitat suitability is categorized into three levels: (1) Good, representing the most suitable conditions for the species; (2) Medium, indicating moderate suitability; and (3) Poor, referring to habitats with little to no suitability for the species. It should be noted, however, that not all species in this study have a specific measurement of habitat patch size, especially those that are mostly found in free-flowing ecosystems such as rivers (the lake sturgeon is a prime example of this). Table 7 displays parameters that would be most suitable to assess the habitat of the bald

eagle, and the tables for the remaining species under consideration for this project can be found in Appendix E.

Parameter	Good	Medium	Poor
Core Area Size	Large (>1.5 km ² , well-defined core)	Moderate (0.8-1.5 km ²)	Small (<0.8 km ² , limited use)
Proximity to Forest	Close to mature/old-growth forests	Scattered tree cover or second-growth forests	Far from forests, urban/suburban settings
Habitat Structure (Nesting and Perching Trees)	Abundant mature trees for perching and nesting	Mixed age trees, some perches available	Few trees for perching, nest trees absent or degraded
Proximity to Water	<3 km from large water bodies	3-5 km from water	>5 km from water, inconsistent access
Proximity to Urban Activities	Minimal to no urban presence	Some nearby development, occasional disturbance	Significant urban presence, high levels of disturbance

Table 7: The parameters that would be most suitable to assess the habitat of a bald eagle, both in terms of habitat (patch) size and quality (Garrett et al., 1993; Wood et al., 1989; Watson, 2002).

Habitat Suitability Matrix Overview. The Habitat Suitability Matrix is a structured approach for assessing how suitable various habitats are for the project's six target species. It utilizes conditional logic to categorize habitats into three distinct levels: high suitability, moderate suitability, and low suitability. Each level is based on specific ecological requirements that align with each species' unique needs, including preferred habitat types, water depth, vegetation, connectivity, food availability, predator avoidance, and sensitivity to human activity.

High Suitability. A habitat is deemed highly suitable when it fulfills all the essential ecological needs necessary for a species' survival, reproduction, and movement.

Moderate Suitability. A habitat is classified as moderately suitable when it satisfies

some, but not all, of the critical ecological requirements. This classification pertains to areas where habitat conditions can support the species, although not to an ideal extent. These moderately suitable habitats are prioritized for conservation and enhancement efforts to improve ecological conditions.

Low Suitability. A habitat is regarded as low suitability, or unsuitable, when it does not provide the necessary features for a species' survival. Recognizing low suitability habitats is vital for directing restoration initiatives and conservation strategies aimed at reducing habitat degradation.

The matrix provides a structured assessment framework by examining each species' specific ecological needs. Conditional "IF-THEN" statements are utilized to assess habitat suitability effectively. For instance, one might state: "IF the habitat consists of marshes with adjacent upland edges, AND the vegetation includes mixed grasses and shrubs, AND there is high connectivity, THEN the habitat is highly suitable for the Eastern fox snake." This approach allows for clear and systematic evaluations of habitat conditions.

This matrix not only helps identify the most suitable habitats but also reveals areas where management or restoration efforts could enhance ecological conditions. The Habitat Suitability Matrix Table is found below in Table 8, which classifies habitat conditions for six target species into three suitability categories: high, moderate, and low. It employs an "IF-THEN" structure to specify the ecological needs that define each category.

Species	Conditions for High Suitability
Lake Sturgeon	IF the habitat = interconnected wetlands, rivers, or deep lakes AND water depth = 0.5 - 13 meters AND substrate = coarse cobble or rubble (64–256 mm) AND flow velocity = 0.6 m/s (optimal), within 0.03–2.51 m/s AND connectivity = high AND pollution = low, THEN high suitability.
Canvasback Duck	IF the habitat = moderate-depth wetlands (Type 3 or Type 4) with dense emergent vegetation (cattails, bulrushes, sedges) AND water depth = 30 - 68 cm AND connectivity to seasonal resources AND low human disturbance, THEN high suitability.
Eastern Fox snake	IF the habitat = marshes with adjacent upland edges AND connectivity = high AND vegetation = dense mixed grasses, shrubs, or herbaceous vegetation AND disturbance = low, THEN high suitability.
Blanding's Turtle	IF the habitat = shallow vegetated wetlands near uplands AND water depth = 50 - 90 cm AND vegetation = dense cattails, floating vegetation, or marshlands AND connectivity = high AND disturbance = low, THEN high suitability.
Bald Eagle	IF the habitat = large trees near open water AND connectivity to roosting areas exists AND disturbance = low THEN high suitability.
Monarch Butterfly	IF the habitat = grasslands, meadows, or conservation fields AND milkweed = abundant (<i>Asclepias spp.</i>) AND nectar plants = plentiful and diverse AND connectivity = high AND pesticide use = low, THEN high suitability.
Species	Conditions for Moderate Suitability
Lake Sturgeon	IF water depth OR substrate partially meets criteria OR flow velocity deviates slightly OR moderate connectivity, THEN moderate suitability.
Canvasback Duck	IF vegetation is suitable but water depth deviates slightly OR wetland connectivity is moderate, THEN moderate suitability.
Eastern Fox snake	IF connectivity is moderate OR vegetation density is low OR some human disturbance is present, THEN moderate suitability.
Blanding's Turtle	IF the habitat has vegetation but lacks connectivity OR water depth slightly deviates from optimal range, THEN moderate suitability.
Bald Eagle	IF habitat = smaller trees OR moderate connectivity THEN moderate suitability.
Monarch Butterfly	IF milkweed is sparse but nectar plants are available OR habitat is partially fragmented OR exposure to low levels of pesticides, THEN moderate suitability.

Species	Conditions for Low Suitability
Lake Sturgeon	IF the habitat = urban OR connectivity blocked by dams OR high water pollution OR substrate unsuitable (e.g., bedrock, heavily silted areas), THEN low suitability.
Canvasback Duck	IF the habitat = agricultural fields, urban areas OR water depth < 15 cm or > 100 cm OR no emergent vegetation OR high human disturbance, THEN low suitability.
Eastern Fox snake	IF the habitat = urban, fragmented landscapes, or developed agricultural fields OR connectivity is blocked OR insufficient vegetation cover exists, THEN low suitability.
Blanding's Turtle	IF the habitat = urban areas, highly fragmented landscapes, or developed agricultural fields OR water depth > 90 cm OR < 50 cm OR lacks essential vegetation, THEN low suitability.
Bald Eagle	IF the habitat = urban OR human disturbance > 660 ft buffer THEN low suitability.
Monarch Butterfly	IF the habitat = urban or highly developed areas, agricultural fields with high pesticide use OR milkweed is absent OR nectar sources are minimal, THEN low suitability.

Table 8: The Habitat Suitability Matrix, which displays species of concern on the left and conditions for suitability on the right.

Long-term Monitoring and Adaptive Management

Criteria	Condition
Habitat area and quality	IF the habitat is well-connected, AND habitat area is higher than 60% of the total area, THEN the condition is GOOD.
Biodiversity and species population	IF 6 key species populations are stable, AND their reproduction is successful, THEN the condition is GOOD.
Contaminant level	IF contaminants level in soil and water keeps below the security level, AND active pollutant mitigation programs are in place, THEN the condition is GOOD.
Community engagement	IF the scenario facilitates regular community engagement, AND public access to eco-tourism and recreation spaces is supported by public amenities on site, THEN the condition is GOOD.
Carbon sequestration and energy usage	IF vegetation cover enables measurable carbon sequestration (e.g., >5 tons CO ₂ e/year per hectare), AND renewable energy is integrated into management operations, AND long-term carbon monitoring exists, THEN the condition is GOOD.

Table 9: The conditions necessary for good performance in long-term monitoring and adaptive management.

Criteria	Condition
Habitat area and quality	IF the habitat is moderately fragmented, OR habitat area is lower than 60% of the total area, THEN the condition is MEDIUM.
Biodiversity and species population	IF monitoring data indicate a decline in at least one indicator species population (e.g., >10% decrease over 5 years), OR species richness falls below 80% of reference ecosystem levels, THEN the condition is MEDIUM.
Contaminant level	IF contaminant concentrations intermittently exceed safe thresholds, OR pollution mitigation program is partially implemented, THEN the condition is MEDIUM.
Community engagement	IF community engagement occurs irregularly, OR public access to recreational areas is available but lacks sufficient amenities, THEN the condition is MEDIUM.
Carbon sequestration and energy usage	IF vegetation cover provides limited carbon sequestration (1–5 tons CO ₂ e/year per hectare), OR renewable energy is only partially integrated into management operations (e.g., covering less than 50% of energy needs), OR carbon monitoring exists but lacks consistency or long-term planning, THEN the condition is MEDIUM.

Table 10: The conditions necessary for medium performance in long-term monitoring and adaptive management.

Criteria	Condition
Habitat area and quality	IF the habitat is highly fragmented, AND habitat area is lower than 60% of the total area, THEN the condition is POOR.
Biodiversity and species population	IF all 6 key species populations are obviously declining, AND their reproduction is unsuccessful, THEN the condition is POOR.
Contaminant level	IF contaminant concentrations intermittently exceed safe thresholds, AND pollution mitigation programs are lacking, THEN the condition is POOR.
Community engagement	IF community engagement is absent, AND public access to recreational areas is very restricted with no amenities, THEN the condition is POOR.
Carbon sequestration and energy usage	IF vegetation cover provides minimal carbon sequestration (e.g., <1 ton CO ₂ e/year per hectare), AND renewable energy is not integrated into management operations, AND carbon monitoring is absent or inconsistent, THEN the condition is POOR.

Table 11: The conditions necessary for poor performance in long-term monitoring and adaptive management.

Species Richness and Diversity. Habitat loss and fragmentation are one of the main drivers of species population decline, with the effect of fragmentation and habitat isolation being thought to decrease species richness (Fahrig, 2003). This is why it is increasingly important to continuously assess the impact of habitat loss and fragmentation on biodiversity and species richness. In the case of this project, several of the project site's habitats for fauna conservation exist within separate patches as opposed to one large habitat. Different habitat patches are known to contribute to overall species richness (Wagner & Edwards, 2001). Species richness assessment should be one of the variables considered in this project's long-term ecosystem monitoring and adaptive management plan in order to properly evaluate the efficacy of habitat restoration plans.

One framework used in numerous studies to evaluate species richness using patch size and fragmentation as considerable variables is the Species-Area Relationship (SAR) framework (Kallimanis et al., 2008; Arnillas et al., 2017). Kallimanis et al. (2008) postulate that habitat diversity correlates with area size. Therefore, greater habitat diversity hosts more species, independent of the area. It should be noted, however, that area and habitat diversity are interrelated and should not be treated as independent variables. In their study, Kallimanis et al. (2008) found a significant correlation between area size and habitat diversity ($R^2 = 0.269$, $p < 0.0001$). The slope of the SAR tends to differ across taxonomic groups. For instance, mobile species like birds may show a different SAR compared to sessile species like plants due to their ability to migrate between patches.

The equation for SAR can be interpreted as shown in (3) (Arnillas et al, 2017).

$$S = cA^z \quad (3)$$

In equation (3), S = species richness, A = habitat area, c = constant (specific to the ecosystem), and z = slope of the species-area curve (typically between 0.2 and 0.4 in natural ecosystems).

Even though larger patches tend to have more species, fragmentation and species turnover modify this relationship. Species turnover (β -Diversity) refers to the degree of dissimilarity among different patches (Baselga, 2010). This indicates that higher turnover means that each patch has more variable species, increasing overall species richness. Meanwhile, lower turnover means that each patch has relatively the same species, contributing to decreased species richness (Arnillas et al., 2017).

Based on these evaluation metrics, an evaluation matrix for species richness was created, based on the SAR formula, as seen in Table 12 below.

Category	Species Richness (S)	Habitat Size (A in km²)	Habitat Diversity (H)	Species-Area Relationship (SAR)
Poor	$S < 10$	$A < 1$	Low (≤ 2 habitat types)	$S = cA^z$, with low c and z values
Medium	$10 \leq S < 50$	$1 \leq A < 10$	Moderate (3-6 habitat types)	$S = cA^z$, moderate c and z values
Good	$S \geq 50$	$A \geq 10$	High (≥ 7 habitat types)	$S = cA^z$, high c and z values

Table 12: The evaluation matrix for species richness based on the Species-Area Relationship formula.

Other methods that are more traditionally used to assess and evaluate species richness and diversity are the Shannon-Weiner and Simpson indices (Magurran & McGill, 2011). However, a study conducted by Roswell et al. (2021) argues the limitations of applying these indices in measuring species diversity, particularly how diversity estimates (particularly richness) based on equal-effort sampling underestimate community diversity from samples that contain fewer individuals. This is due to how samples often include fewer species by chance alone, regardless of the community from which they are drawn (Gotelli & Colwell, 2001).

Instead, Roswell et al. (2021) proposes a different framework to evaluate species richness, called the Hill diversity framework, which generalizes conventional indices into a single formula that allows for more intuitive and comparable measurements. This framework consists of two sub-formulas: 1) The Hill-Shannon Diversity index (D_1), and 2) the Hill-Simpson Diversity index (D_2). Hill diversity allows comparisons across time while ensuring interpretability, e.g., a Hill-Shannon value of 10 would mean the community is as diverse as a perfectly even community with 10 species (Roswell et al., 2021).

Roswell et al. (2021) in their framework recommend coverage-based rarefaction, which standardizes samples by their completeness rather than by effort or sample size. This method is also partly based on the estimator from Chao & Jost (2012), which ensures fair comparisons across different sampling efforts and time periods. This method of evaluation is suitable for long-term species evaluation, with a habitat restoration project such as this one being a perfect example. By integrating these methods, ecologists can make more informed decisions in monitoring and adaptive management plans for ecosystem recovery, particularly through refining hypotheses and models of biodiversity response to scale and global change, which local richness alone can, famously, fail to illustrate clearly (Cardinale et al., 2018).

The formula for the Hill diversity indices can be interpreted as shown in (4) below.

$$D_q = (\sum_{i=1}^S p_i^q)^{\frac{1}{1-q}}$$

(4)

With $q=1$ (Hill-Shannon), the equation is as follows in (5).

$$D_1 = e^{H'} = e^{-\sum_{i=1}^S p_i \ln p_i}$$

(5)

With $q=2$ (Hill-Simpson), the equation is as follows in (6).

$$D_2 = \frac{1}{\sum_{i=1}^S p_i^2}$$

(6)

Subsequently, standardized comparisons using sample coverage will also be used to ensure fair biodiversity assessments despite different sampling efforts across years. The formula is derived from Chao and Jost's (2012) estimator formula, which is seen below in (7).

$$C = 1 - \frac{f_1}{n} \left(\frac{n-1}{n-f_1+2f_2} \right) \quad (7)$$

Where, in (7), f_1 = number of species represented by only 1 individual (singletons), f_2 = number of species represented by only 2 individuals (doubletons), and n = total individuals sampled.

Based on the frameworks described above, an evaluation matrix for species diversity assessment has been subsequently created for this project, based on the Hill diversity indices. This matrix will be further integrated into the project's long-term monitoring and adaptive management plan. Like the other parameters of the monitoring and adaptive management plan, the evaluation matrix consists of three categories of performance: good, medium, and poor.

Category	Species Richness (S)	Hill-Shannon Diversity (D1)	Hill-Simpson Diversity (D2)	Coverage-Based Rarefaction (C)	Evenness	Beta Diversity
Poor	Low species richness (few species present)	$D1 \leq 5$ (low diversity, high dominance by a few)	$D2 \leq 2.5$ (one or two species dominating the community)	$C < 0.85$ (many species not sampled properly)	Evenness < 0.5 (few species dominate heavily)	Low beta diversity (< 0.4), low little species turnover over time
Medium	Moderate species richness (fair amount of species present)	$5 < D1 \leq 10$ (moderate diversity, some form of dominance)	$2.5 < D2 \leq 5$ (some species are more dominant than others)	$0.85 \leq C \leq 0.95$ (sample represents the community fairly well)	Evenness between 0.5 and 0.8 (some species dominate)	Medium beta diversity (0.4 - 0.7), partial species turnover over time
Good	High species richness (many species present)	$D1 > 10$ (high diversity with balanced species distribution)	$D2 > 5$ (dominant species not overly abundant)	$C > 0.95$ (most species in the community are represented)	Evenness close to 1 (species abundances are similar to one another)	High beta diversity (> 0.7), indicating diverse species replacement over time

Table 13: The evaluation matrix for species richness based on the Hill diversity indices.

Human Use

True community engagement was not possible as part of this project. As a result, the first aspect of the human connectivity variable that was researched was investigating what community engagement strategies might look like for a site like this one. Following this, some alternatives to true community engagement were researched. Combining the outcomes of these two research methods established a better understanding of what should occur when designing futures for a site, like what is under consideration here. Once this was established, research into what the communities surrounding the project site are like, and what they might desire, was conducted.

This ultimately led to the input for the alternative scenario design process of what human communities might desire for the project site.

Literature Review

Equity

Community engagement is crucial when working to design a new use for a potentially contaminated site, as under consideration here. Before any engagement starts, however, it is important to ensure that engagement strategies are not based around any assumptions, no matter how well-intended they are. Common assumptions made on community engagement can include researchers and community members having the same goals, educating residents being essential to gaining community support, that the community will benefit from the restoration effort, and that the community has solutions to contribute to the technical aspects of the restoration effort (Cross & Chappell, 2022). While these assumptions are not inherently malicious in nature, starting off with them in mind can limit the scope of community engagement efforts. Keeping these elements in mind as engagement strategies are planned is crucial, and can help to inform a more holistic engagement strategy.

Along with recognition of assumptions, considering other engagement strategies in brownfield remediation, such as at Superfund sites, can help to inform best practices. At one Superfund site in Phoenix, Arizona, there was almost three decades of poor communication between the community and state agencies and minimal corporate-led remediation, generating mistrust (Foley et al., 2017). Once trust is lost in a community, it is difficult to regain it, showing the importance of establishing and maintaining trust. If there is no trust present, then engagement strategies will likely not be effective, and the agency-facilitated meetings for this site showed low attendance during the mentioned three decades (Foley et al., 2017). When designing an

engagement strategy, establishing trust is crucial, which is made possible with details like sticking to a timeline and open communication. Open communication can and should be accomplished in a variety of ways, as simply sharing information at a town-hall style meeting may not reach the full community, but providing web-based information, flyers or posters, and in-person meetings can increase the scope of awareness.

Another site in which trust is key is another Superfund cleanup project in Montana. Here, it is noted that trust can be shown to increase with public participation, but can also decrease if that participation is not “truly deliberative” (Metcalf et al., 2015). Simply informing community members of plans for a site is not enough, and creating spaces to get feedback that is then incorporated is one way to work towards a deliberative process. An additional important note is that smaller projects can have higher participation, and more flexibility to integrate goals and enable personal interactions (Metcalf et al., 2015). The site in question here is smaller in scope, and so any engagement strategy planned here could aim for the factors outlined with smaller projects. These strategies should, however, be planned so that they are truly deliberative, potentially beyond traditional meeting set-ups.

Transparency

Community engagement is important for the success of redeveloping contaminated sites (i.e. Brownfield or Superfund), but factors such as an information gap, unequal power, and low participation hinder community engagement’s contribution to the redevelopment process (Lehigh et al., 2020). There have been several efforts at the federal or state level to improve community engagement in Brownfield or Superfund site redevelopment. The National Institute of Environmental Health Sciences has a Superfund Research Program (SRP) to fund university research. The SRP requires investigators to interact with the affected communities and translate

research findings for these communities' uses (Trottier et al., 2019). For example, Brown University used a grant from the SRP to engage a Tiverton, Rhode Island community in 2006 and collaborated with activists to earn each qualified household \$25,000 compensation for the contaminated site's redevelopment (Senier et al., 2008). One factor that can lead to issues, such as an information gap and low community participation, is lack of transparency. Redeveloping a contaminated site often involves multiple stakeholders, so establishing transparency is crucial for effective communication, the sense of trust, and meaningful community engagement (Ramirez-Andreotta et al., 2014).

Building transparency is important at all stages of the community engagement process of contaminated site redevelopment. Forming a transdisciplinary team needs to be transparent so that each team member's expertise and value receive respect and all stakeholders aim to come up with a unified solution (Ramirez-Andreotta et al., 2014). Transparency is also essential for all communications among team members because each type of stakeholder, like the regulatory agency, the community, academic researchers, or others, uses a specific communication method. Transparent communication helps create a community-based, open collaboration environment and reduces the sense of power inequality (Ramirez-Andreotta et al., 2014). Lastly, transparency requires regulatory agencies and researchers to share their results, suggestions, and decisions with the community and avoids the site redevelopment process from becoming solely expert-driven and ignoring community members' lay knowledge (Cohen et al., 2011).

Given transparency's importance, there are no widely accepted criteria or definitions of what "good" transparency is, since it is a qualitative variable and subject to each person's subjective interpretation. Therefore, recent studies on improving transparency during contaminated site redevelopment focused on individual cases. For example, the harbor area near

Bergen, Norway had PCB contaminations (Sparrevik et al., 2011). There were five remediation alternatives, including using capping and dredging techniques. Sparrevik et al. (2011) proposed a multi-criteria involvement process (MIP) composed of objectives, criteria metrics, performance measurement, and information synthesis to evaluate transparency for this Bergen case. The study found that MIP contributed to improved transparency because it made the community involvement process more structural, well documented the criteria for a reasonably feasible remediation alternative, and helped community members learn ways of effective engagement with regulatory agencies (Sparrevik et al., 2011).

Another case looked at the Motorola 52nd Street Superfund Site in Phoenix, Arizona that had carcinogenic trichloroethylene contaminations (Foley et al., 2016). The original remediation alternative was extracting and then treating trichloroethylene. In this area, 62% of residents were Latino and 21% of community households earned less than \$10,000/year, and poor information sharing and limited remediation efforts led by corporates made the surrounding communities suspect that the regulatory agencies had unlawful relations with corporates (Foley et al., 2016). Due to communities' distrust, Foley et al. (2016) proposed a multi-stakeholder collaboration scheme consisting of collaboratively framing the contaminant problem, collaboratively setting the remediation goal, and creating & implementing evidence-supported remediation strategy. This scheme could improve transparency by rebuilding trust, stimulating momentum, and recreating the power symmetry.

Possible Community Engagement Strategies

There are a variety of possible strategies for community engagement that can lead to a deliberative process, with one being the use of a charrette session. This can look to engage a variety of stakeholders early on in the process, and can synthesize the contributions of all

stakeholders (Cundy et al., 2013). Planning such a session should work to avoid the previously mentioned assumption that the community has solutions for the technical aspects of the restoration effort (Cross & Chappell, 2022). One possible way to avoid this could be planning other engagement methods before a charrette, to gauge what timing might be best for community members to attend, to ensure awareness around aspects of the site, and to gauge interest in proposing design ideas in an intensive format like a charrette. Other community engagement efforts, like roundtable discussions, focus groups, surveys, or interviews, can provide design ideas. These efforts may be better suited if members of the community do not have the time to commit to a charrette session, but can increase the timeline between community ideation or feedback and implementation in design.

Establishing a community engagement strategy that goes beyond traditional meetings requires proper planning of events and how best to reach the community. Appropriate planning of engagement events should be informed by knowledge of the target community, which can then lead to open communication between all stakeholders (Ramirez et al., 2024). Knowledge of who the targeted responders are can inform event scheduling and content, as with the charrette session. For scheduling, this can include selecting a neutral location or timing so that as many people can attend as possible (Foley et al., 2017). Addressing attendance concerns may include knowledge of public transit schedules, so that community members are able to get to and from the event, knowledge of internet access in the community if planning web-based engagement, or knowledge of childcare availability, to name a few. Other aspects can certainly be addressed, but keeping these pieces in mind can ensure that attendance is not limited for community members beyond their desire to attend and participate.

Identification of key stakeholders can also play a key role in a community engagement strategy. If using options like focus groups or workshops, identifying key stakeholders for these can lead to an equitable representation of stakeholders, which is one step for having all opinions represented (Rizzo et al., 2024). Doing so means that planning does not stop after the first event of a strategy, but continues throughout the process. If events are planned in a town-hall format, but this does not provide enough space for proper discussion, then the strategy will likely need to be revisited. Another option besides focus groups to provide this space, if there is sufficient internet access, is a web-based survey or similar instrument. This could also be a planned step of the engagement process, informed by workshops or focus groups to see what the wider community thinks (Rizzo et al., 2024). Planning for a combination of these methods can provide the widest range of community input, ideally without an inequitable contribution from some stakeholder groups.

An important way to inform planning of community engagement strategies is by looking at the demographics of the community in question. As discussed earlier, Trenton is primarily white and of approximately median income, with about a quarter of the population above 65. Using these demographics to inform a community engagement strategy is one way to work towards equitable input from all community members (Phillips, 2021). Demographic data can potentially be looked at at the census block or tract level to inform what members of the community might be best to target for an equitable engagement strategy. This also can include those who may have been most impacted by the historical use of the TCPP or those who lack access to greenspace.

Without being able to carry out community engagement strategies, one way to envision what responses could be is to look at a similar community's use of greenspace. In Québec City,

there is a similar proportion of older adults as there is in Trenton, and their preferences for greenspace can inform what those in Trenton might want (Audate et al., 2024). While this may not be true if true community engagement is carried out, the preferences for those in Québec City include safety features and maintenance, with a need for social factors to align for individuals to use the space (Audate et al., 2024). Of course, what these social factors are would be informed through proper community engagement. Assuming the same desires from one community to another is not a proper substitute for these efforts in a real-world scenario.

One possible method to follow up a hypothetical community engagement strategy would be continued community involvement at this space, if made into a park or including human use. In a study from Philadelphia, residents were more likely to have a stronger perception of the park as a “community asset” the more engaged they felt with the park’s staff and operation (Mullenbach et al., 2019). Community engagement during the design process is important, but continuing this engagement after this has been implemented is essential to build a space for the local and regional communities. One way to do so would be to partner with existing organizations, which can connect the new greenspace to organizations community members already have ties with. This could potentially grow the reach of the space beyond what was created during any design phase community engagement and help to ensure any implemented design can be a space for community members to use and gather at.

Assessment Matrix

With consideration for human usage, assessment can be conducted using categorical binary variables, where each is either a yes or a no. The first main category for this considers the points of access that exist at the site. The four types considered are if there is a connection point to the Iron Belle or North/South trail, a connection point to Elizabeth Park, an access point

unique to the site for non-vehicle transport methods, and an access point for vehicle transport methods. The second main category focuses on amenities within the alternatives. This focuses on if there are amenities not seen at other parks in the area in the alternative, which are tennis court(s), pickleball court(s), and/or water park or splash pad. Finally, consideration is given for safety and accessibility given what is known about the demographics of the surrounding areas. This includes lighting and ensuring that there are spaces to sit. Any additional considerations would require community engagement or other feedback mechanisms. These are intended to be safe assumptions given what is known about the surrounding community, their park access, and possible desires for a new space.

To compare with other matrices for the integrated assessment, the following scale was used. As there are 12 indicators, meeting 0 to $\frac{1}{3}$ (4) indicators is the first rung of the scale (a 1), meeting $5 - \frac{2}{3}$ (8) indicators is the second (a 2), and meeting 9 - all indicators is the third (a 3).

Remediation Techniques

The remediation variable aims to assess potential soil and groundwater contamination at the decommissioned TCPP site based on consideration of similar sites and develop a comprehensive remediation plan to ensure environmental safety for future development and use.

The Michigan Department of Environment, Great Lakes, and Energy (EGLE) is the primary agency responsible for overseeing and implementing brownfield-related cleanup and redevelopment projects in Michigan, operating under the Natural Resources and Environmental Protection Act. This legislation establishes the responsible parties, cleanup standards, and procedures to ensure the safety of land and groundwater.

EGLE provides cleanup standards and procedures for contaminated sites. The establishment of cleanup objectives is based on aligning risk assessment results with the

anticipated land use, specifying the required reduction levels of contaminants in various site areas to ensure the land is suitable for future use without posing risks to human health and the environment. Following the determination of cleanup objectives, specific remediation plans will be developed to achieve these goals. Depending on the types of contaminants and site characteristics, various remediation measures may be employed, including physical, chemical, or biological methods.

In this project, during the formulation of cleanup objectives and remediation plans, the risk assessment phase involves evaluating the site's contamination levels and potential risks. Due to the academic nature of this project, on-site soil and groundwater sampling analyses are not feasible. Therefore, the assessment of contaminant types and distribution will primarily rely on historical industrial activity records, existing environmental data from the project site, and comparison to similar sites. In this section, corresponding remediation measures and plans based on considerations of human health, the health of the six animal species, and environmental health will be proposed, addressing the assumed contamination scenarios.

Literature Review

Remediation techniques vary widely, and for the same site, different areas can be treated using appropriate technologies based on pollution conditions. In some cases, multiple techniques may be combined to achieve cleanup goals. The selection of feasible remediation technologies relies heavily on treatability studies, which consider factors such as the type and extent of contamination, remediation objectives, site characteristics, cost-effectiveness, implementation time, and public acceptance (Liu et al., 2018).

Remediation techniques are generally categorized into two types based on spatial application: in-situ and ex-situ remediation.

In-situ remediation does not require excavating contaminated soil or transporting it to an off-site treatment facility, minimizing soil disturbance and reducing exposure risks for workers and nearby communities. This method can also significantly lower remediation costs (Liu et al., 2018). However, site-specific conditions, such as weather, soil permeability, contamination depth, and potential deep leaching of chemicals, must be carefully considered (Olexsey & Parker, 2006).

Among in-situ techniques, capping is one of the most common methods. It is a cost-effective, non-invasive approach for remediating contaminated sediments. This technique typically involves placing sandy materials (e.g., clean sediments, sand, and gravel) or amendments (e.g., apatite, phosphate rock, lime, and zeolite) in layers or mixed in specific proportions over contaminated sediments (Peng et al., 2018). Capping is environmentally friendly and cost-efficient (Peng et al., 2018), effectively isolating contaminants, limiting human exposure, and preventing further pollutant spread. However, its major drawback is that it does not actively remove contaminants but merely reduces exposure risk (Liu et al., 2018). Over time, capping layers may degrade, become uneven, or be damaged, posing a potential threat if pollutants are left untreated. To enhance its effectiveness, active capping materials such as apatite, clay, zeolite, and activated carbon have been used to chemically interact with contaminants (Peng et al., 2018).

Ex-situ remediation involves physically extracting contaminated media from the site and transferring it elsewhere for treatment (Kuppusamy et al., 2016). One of the most common and conventional ex-situ methods is "excavation and haul," where contaminated soil is excavated and transported off-site. This technique is costly but allows for rapid and highly efficient contaminant removal. It is easy to monitor and ensures uniform treatment (Kuppusamy et al., 2016), making it

suitable for areas with severe contamination or where land use requires minimal pollutant exposure.

These two traditional methods offer the most straightforward approach—either covering or removing contaminants. However, they do not degrade or neutralize the pollutants. In contrast, more advanced remediation techniques rely on containment, extraction/removal, and immobilization mechanisms, utilizing physical, chemical, biological, electrical, or thermal processes to mitigate contamination (Liu et al., 2018). These techniques can be combined with traditional methods, where the latter provides short-term isolation while treatment-based approaches support long-term remediation.

Groundwater Treatment Techniques

Groundwater contamination by heavy metals presents a serious risk to human health and the environment. These metals, which may come from industrial sources or occur naturally, can remain in groundwater for long durations, making remediation a vital priority. According to Hashim et al. (2011), groundwater remediation technologies can fall into three main categories: chemical, biological, and physico-chemical treatment methods.

According to Hashim et al. (2011), chemical treatment methods typically aim to modify the chemical characteristics of heavy metals to lessen their toxicity and mobility. One technique involves in-situ reduction, where reductants such as dithionite are injected into areas of contamination. This process creates a reducing environment that converts heavy metals into less soluble forms and immobilizes within the soil. Another approach utilizes iron, which is readily accessible and environmentally benign. Zero-valent iron (ZVI) can directly reduce heavy metals like chromium, transforming them into less toxic and more stable forms. Moreover, ferrous salts

can be used to decrease chromium's toxicity, facilitating its precipitation and removal from groundwater.

In certain situations, it may be necessary to remove contaminated soil physically. Soil washing is a method that involves separating the soil by particle size and washing the finer particles, where heavy metals usually accumulate. The water used for washing containing the extracted metals is treated separately afterward. In-situ flushing provides an alternative to excavation, wherein fluids, commonly dilute acids or chelating agents like EDTA, are pumped through the contaminated area to dissolve and extract heavy metals. The resulting metals are removed, and the fluid is pumped out. Finally, chemical fixation seeks to immobilize heavy metals in the soil to prevent their movement and further contamination. This can be accomplished using materials like red mud, which binds to heavy metals, or specific chemical reactions that help trap the metals within the soil structure (Hashim et al., 2011).

Biological treatment methods utilize the natural ability of certain organisms to remove or contain heavy metals (Hashim et al., 2011). This process employs microorganisms, such as aerobic bacteria, to break down contaminants in oxygen-rich groundwater. Some plants, known as hyperaccumulators, can absorb significant amounts of heavy metals from the soil and groundwater, effectively removing these contaminants through harvesting.

To enhance these natural processes, scientists use techniques like enhanced bioremediation. This involves initially pumping out the contaminants and then introducing nutrients and oxygen into the groundwater to stimulate the growth of beneficial bacteria. Introducing specific microflora, such as bacteria or fungi, can further improve plant metal uptake. Biological sulfate reduction (BSR) uses sulfate-reducing bacteria to convert sulfate in the water into sulfide. This sulfide then reacts with heavy metals, forming insoluble metal sulfides

precipitating out of the water. BSR is particularly effective for treating acid mine drainage, where high sulfate concentrations and heavy metals coexist. Another biological approach is biosorption, which uses natural materials like algae, plant matter, or DNA to adsorb heavy metals from contaminated water. These materials serve as natural filters, effectively removing metals through their unique surface properties (Hashim et al., 2011).

Physico-chemical treatment technologies integrate physical and chemical methods to clean contaminated groundwater (Hashim et al., 2011). One notable method uses permeable reactive barriers (PRBs), underground structures built from reactive materials to capture and treat polluted water. These barriers utilize various processes, including sorption, chemical reactions, and biological treatment, to eliminate heavy metals from the water. Common materials found in PRBs include zeolites, red mud, activated carbon, ZVI, compost, and limestone. Additionally, other techniques in this field involve the application of surfactants to improve heavy metal removal, as well as the use of membranes and filters to isolate and concentrate contaminants. Activated carbon is often utilized for its excellent adsorption properties (Hashim et al., 2011).

Electrokinetic Remediation. Electrokinetic remediation (EKR) is an advanced method for extracting contaminants from soil and groundwater, demonstrating significant effectiveness in low-permeability soils such as kaolinite. Traditional techniques, including soil washing and bioremediation, often struggle in these conditions due to challenges in delivering treatment agents (Maturi & Reddy, 2006; Maturi & Reddy, 2008). EKR functions by applying a direct current electric field across the contaminated zone, triggering various electrokinetic processes such as electromigration, electroosmosis, and electrophoresis, which facilitate the removal of pollutants (Maturi & Reddy, 2008).

Electromigration entails the movement of charged ions in the pore water of the soil toward the electrodes. Heavy metal contaminants, which are positively charged, travel toward the cathode (negative electrode), while negatively charged ions are attracted to the anode (positive electrode). In contrast, electroosmosis refers to the bulk flow of water through the soil pores, mainly from the anode to the cathode (Maturi & Reddy, 2008). This movement is influenced by the electric field interacting with the charged surfaces of the soil particles, aiding in the transport of contaminants. Electrophoresis involves the movement of charged particles or colloids within the pore water toward the electrodes (Maturi & Reddy, 2008).

EKR can effectively address a variety of contaminants, including heavy metals and organic contaminants. The method has successfully eliminated heavy metals like nickel, mercury, lead, and cadmium (Maturi & Reddy, 2006; Maturi & Reddy, 2008). Additionally, EKR effectively treats organic pollutants, particularly PAHs such as phenanthrene (Maturi & Reddy, 2006; Maturi & Reddy, 2008).

Several factors impact the effectiveness of EKR on different contaminants. The charge, solubility, and chemical nature of the contaminant determine how it responds to the electric field (Maturi & Reddy, 2008). For instance, neutral organic compounds like phenanthrene may require enhancements like cosolvents to improve their solubility and transport (Maturi & Reddy, 2008). Factors such as mineral composition, hydraulic conductivity, and pH significantly affect EKR's performance (Maturi & Reddy, 2008). Soils with low organic matter, like kaolinite, may have reduced efficacy in removing organic contaminants due to limited sorption to the soil matrix (Maturi & Reddy, 2008). The success of EKR also relies on optimizing factors such as applied voltage, treatment duration, and the choice of extracting solution to achieve the best removal efficiency (Maturi & Reddy, 2008).

Furthermore, several challenges hinder the full potential of EKR. Differences in soil characteristics, including mineral content, hydraulic conductivity, and pH, can lead to inconsistent contaminant removal (Maturi & Reddy, 2008). Scenarios with mixed contaminants, involving both heavy metals and organic substances like PAHs, make it difficult to choose the right extracting solutions and to optimize operational parameters (Maturi & Reddy, 2006; Maturi & Reddy, 2008). For example, using n-butylamine as a cosolvent for enhanced phenanthrene removal can precipitate nickel, complicating its extraction. Aspects such as soil characteristics, applied voltage, and enhancement agents can restrict electroosmotic flow, which decreases the movement of contaminants toward the electrodes (Maturi & Reddy, 2008). Electrochemical reactions occurring at the electrodes can modify the pH and chemical composition of the soil surrounding them, leading to challenges such as the precipitation of heavy metals, which immobilizes the contaminants and complicates their removal (Maturi & Reddy, 2008). Traditional EKR systems often depend on grid electricity, resulting in high energy costs that limit their viability for large-scale applications (Maturi & Reddy, 2008).

EKR is a valuable technique for tackling soil contamination with low permeability, as it employs electrokinetic processes to extract various pollutants. However, its application faces obstacles, including significant energy requirements and the diverse nature of soil and contaminant characteristics. Addressing these issues is vital for broadening the use of EKR. A potential approach is incorporating renewable energy sources like solar power, which can offer a sustainable and cost-efficient energy solution. The following section will examine how combining renewable energy and remediation technologies can enhance the practicality and environmental benefits of remediation efforts, paving the way for innovative solutions to challenging environmental problems.

Renewable Energy and Remediation Technologies. Combining renewable energy sources with groundwater remediation provides an environmentally friendly and cost-effective method for cleaning contaminated sites. Solar energy, in particular, has demonstrated substantial potential as a power source for EKR, a reliable technique for addressing polluted soil and groundwater.

Solar PV panels can directly supply energy to EKR systems, which reduces dependence on conventional power sources while lowering operational costs and environmental harm. Zhou et al. (2024) highlighted the success of solar-powered EKR, achieving an impressive cadmium removal efficiency of 90.24% from contaminated soil. Their research also points to the financial benefits of using solar energy for EKR compared to systems relying on grid electricity.

Variations in solar energy output may impact the electric potential gradient necessary for effective EKR, which could reduce system efficiency. To address this limitation, Baek et al. (2012) investigated pulse-mode electrokinetic remediation, which can function effectively even with a sporadic power supply. However, adding solar panels and batteries increases the complexity of the overall remediation setup.

Although solar energy is a key player, other renewables such as wind power, biomass, geothermal energy, and fuel cells also present opportunities for integration into groundwater remediation systems (Baek et al., 2012). New technologies, such as sediment microbial fuel cells, offer the dual advantages of remediating contaminants while generating electricity through microbial processes within sediments (Hong et al., 2009; Hong et al., 2009; Williams et al., 2009; Jiang et al., 2010; Yuan et al., 2010; Huang et al., 2011).

Electrochemical remediation methods, including EKR, align with green remediation principles by minimizing the need for chemical additives compared to conventional techniques

(Baek et al., 2012). When paired with renewable energy sources, this strategy further reduces reliance on fossil fuels, significantly lowering the carbon footprint and greenhouse gas emissions associated with remediation activities.

In all, the practical application and effectiveness of integrating renewable energy into groundwater remediation are influenced by specific site characteristics. Factors such as solar irradiance, wind patterns, geothermal resource availability, and the space available for infrastructure must be thoroughly evaluated to identify the most appropriate renewable energy source and system design for each situation.

Groundwater Technology Conclusion. Selecting the most appropriate technology for groundwater remediation involves several factors, including site characteristics, types and concentrations of contaminants, and cost-effectiveness. Iron-based technologies, such as ZVI, red mud, and ferrous salts, have attracted considerable attention due to their versatility and effectiveness in reducing, precipitating, and adsorbing heavy metals. Biological and biochemical methods, especially those that employ microbes and nutrients for processes like bioprecipitation, enzymatic oxidation, biosurfactant production, and sulfate reduction, present promising sustainable solutions for heavy metal remediation.

Groundwater remediation is a complex and continuously evolving field. Ongoing research and development aim to optimize existing technologies and investigate new, sustainable, environmentally friendly, cost-effective approaches. The future of groundwater remediation will likely involve integrating various technologies, carefully considering site-specific conditions, and implementing long-term monitoring strategies to ensure the success and sustainability of remediation efforts.

Phytoremediation

Phytoremediation is a biological method that employs plants and their accompanying microbes to alleviate environmental pollution. This technique utilizes natural biological mechanisms to stabilize, extract, break down, or vaporize pollutants from soil, water, and air, such as metals, organic materials, and radionuclides. It has garnered interest as an environmentally friendly and economical alternative to conventional remediation methods, especially for sites with varying contamination levels (Pilon-Smits, 2005).

One of the most significant benefits of phytoremediation is its cost efficiency (Pilon-Smits, 2005). In contrast to mechanical and chemical remediation approaches, like soil excavation or pump-and-treat systems, phytoremediation is considerably more affordable. Estimates indicate it can be as much as ten times less expensive than traditional methods. This financial advantage has made it a favored option for large-scale initiatives, particularly in areas with constrained financial resources. Furthermore, phytoremediation's dependence on plants allows for in situ application, doing away with the necessity for extensive soil transport, which further minimizes costs and the possibility of secondary pollution (Pilon-Smits, 2005).

The ecological advantages of phytoremediation are also considerable. By incorporating plants into polluted areas, this approach cleans up contaminants, improves local aesthetics, and aids in ecosystem restoration. The plant cover can stabilize soils, prevent erosion, and enhance biodiversity. In addition, phytoremediation has gained public approval as an environmentally friendly technology. Unlike mechanical or chemical remediation techniques, which may be considered intrusive or industrial, phytoremediation projects are often regarded as ecologically friendly and socially acceptable (Pilon-Smits, 2005).

Phytoremediation includes a variety of strategies designed for specific pollutants and environmental conditions (Pilon-Smits, 2005). Phytoextraction involves plants taking

contaminants into their biomass, which can be harvested and safely discarded or repurposed. Phytostabilization entails using plants to immobilize pollutants in the soil, thereby diminishing the risk of erosion or leaching. Phytodegradation refers to the enzymatic breakdown of pollutants by plants, while phytovolatilization pertains to transforming contaminants into volatile forms emitted into the atmosphere. Rhizofiltration uses plants in hydroponic systems to purify pollutants from water. Each of these strategies capitalizes on the innate abilities of plants and their microbial rhizospheres to effectively tackle environmental pollution (Pilon-Smits, 2005).

In addition to its environmental benefits, phytoremediation also plays a critical role in landscape design, particularly in brownfield redevelopment. By integrating vegetation into remediated landscapes, designers can create multifunctional spaces that prioritize ecological safety while supporting public use. For example, as Erdem & Nassauer (2013) point out, incorporating native plants and visible remediation features can cue users to the history of contamination while ensuring safe human interaction with these sites. This approach aligns with the precautionary design principle, addressing residual contamination through ecological processes and thoughtful landscape design.

Although phytoremediation offers numerous benefits, it also faces several challenges. A major limitation is the reliance on the depth of plant roots; many plants have shallow root systems that may not reach deeply buried contaminants, resulting in some pollutants remaining untreated (Pilon-Smits, 2005). Furthermore, phytoremediation can be a lengthy process. While certain aspects, such as microbial degradation in the rhizosphere, can occur within days or months, others, like phytoaccumulation for cleaning soil, may take years due to the complexity and availability of the pollutants (Pilon-Smits, 2005).

Another significant factor is the bioavailability of pollutants. For phytoremediation to succeed, contaminants must be accessible to plant roots and their associated microbes. However, some pollutants can tightly bind to soil particles or exist in forms difficult for plants to absorb. In such cases, adding soil amendments to improve the bioavailability of these pollutants might be necessary, which can complicate the remediation process and increase its costs (Pilon-Smits, 2005). Various site-specific factors, including soil toxicity, pH levels, and climate conditions, can also influence the effectiveness of phytoremediation. In some extreme scenarios, these factors might prevent plant growth altogether, requiring additional treatments or alternative remediation methods (Pilon-Smits, 2005).

Bioaccumulation raises significant ecological concerns in contaminated areas, especially those affected by industrial waste. For instance, fly ash dump sites can introduce heavy metals and organic pollutants into food chains. These contaminants, such as PAHs and heavy metals, may accumulate in living organisms, leading to health risks due to biomagnification (Yadav et al., 2021). Studies at the Big Marsh site showed that Little Bluestem (*Andropogon scoparius*) absorbed metals like lead, chromium, and zinc within its tissues (Reddy et al., 2017). Lead and chromium were mainly confined to the roots. At the same time, manganese and zinc moved to the plant's upper parts, highlighting their role in remediating contaminants and creating pathways for these metals to enter higher trophic levels (Reddy, Amaya-Santos, & Cooper, 2017). Residual contamination can pose long-term risks to ecosystems. Even after remediation efforts, contaminants often linger in revitalized brownfield sites, potentially bioaccumulating wildlife and making their way into the human food chain. These residual contaminants may go unnoticed or be sufficiently addressed by policies focusing more on human health than broader ecological concerns (Erdem & Nassauer, 2013).

In summary, phytoremediation is a promising strategy for tackling environmental contamination. Its advantages, including cost-effectiveness, environmental friendliness, and public support, make it appealing for many remediation initiatives. However, its limitations, such as reliance on root depth, the time-consuming nature of the processes, and challenges related to pollutant bioavailability, emphasize the need for meticulous planning and site evaluation. Integrating phytoremediation with other remediation strategies and customizing approaches to specific site conditions can enhance its effectiveness while reducing potential risks.

Precedent Review

Landschaftspark Duisburg-Nord. Landschaftspark Duisburg-Nord is located in Duisburg, Germany, in the Ruhr area. This project successfully transformed an abandoned steel plant into a multifunctional public space. The plant, which was used for iron production, relied on the region's coal resources and the Rhine River transportation network. After closing in 1985, the site was left with large industrial structures, abandoned buildings, and severely polluted soil and groundwater.

Landscape designer Peter Latz proposed innovative landscape restoration strategies in the 1990s. These strategies focused on three methods for improving soil and groundwater: capping, excavation and hauling, and phytoremediation. For capping, investigations found severe soil damage, with toxic substances extending deeper than ten meters, making plant growth impossible. To remedy this, asphalt and other materials were used to seal the contaminated soil, and a new water transport system was implemented on top to prevent surface water from further polluting the soil (Hu, 2017). For less contaminated soil, the top layer was excavated and replaced with new soil, organic fertilizers were applied, and nutrients were regularly delivered to encourage the growth of pollution-resistant plants. Biological activity, microbial decomposition,

and plant growth accelerated the soil's natural recovery (Hu, 2017). Finally, for phytoremediation, hyperaccumulator plants such as reeds, poplars, and herbaceous plants were used to absorb heavy metal pollutants. Additionally, an artificial wetland system was created to degrade pollutants and purify groundwater with the help of aquatic plants and microorganisms.

In terms of land use, the site was developed into a comprehensive public space, including industrial heritage displays, a museum in a repurposed factory building, open parkland, recreational areas for activities like climbing and diving, and ecological education and experimental zones. These restoration strategies have led to the gradual recovery of the ecosystem, with the site being reactivated as a public space. However, the project does have limitations, through the drawbacks of the capping technique and the impact of climate change. While the asphalt layer from the capping remediation method sealed the contaminated soil, deep contamination remains. Over time, the asphalt layer has deteriorated, increasing the risk of pollutant exposure. Increasing extreme weather events in Europe, such as heatwaves and heavy rainfall, have affected the park's vegetation and hydrological systems, requiring adjustments to management strategies.

Based on this project, further investigation into deeper soil remediation techniques, combined with capping, could balance the site's immediate usability with long-term sustainable recovery. Optimizing management strategies for plant remediation, such as introducing drought-resistant plant communities, could also help address climate challenges.

Gas Works Park. Gas Works Park is located on the north shore of Lake Union in Seattle, Washington, covering approximately 8.3 hectares. The site was once a gas plant that provided lighting and fuel for the city of Seattle. The plant ceased operations in the 1950s and was abandoned, leaving behind significant soil and groundwater contamination. The soil

contained pollutants such as petroleum and xylene, with industrial waste deposits up to nine feet thick across the park (Way, 2013).

Landscape architect Richard Haag led the design of the park, transforming the industrial site into a unique public space while preserving its historical features. The soil remediation strategies included bioremediation, capping, and a self-sustaining remediation system.

For bioremediation, sawdust and organic materials were mixed with contaminated soil to introduce oxygen to the surface. In acidic areas, sewage sludge, biomass, leaves, and free fly ash from a cement plant were added to improve the soil, allowing bacteria to work and helping plants survive in soil that had not supported vegetation for decades (Way, 2013). For the capping method, Haag piled the most severely contaminated soil and unrecoverable construction waste together and covered it with 18 inches of hard clay to isolate the pollutants and prevent further spread (Way, 2013). Finally, the self-sustaining remediation system can be seen through the way in which remaining parts of the site were designed with rolling hills and valleys to promote the dynamic breakdown of pollutants. The hills helped to maintain water flow, while valleys allowed water to penetrate, interacting with active bacterial zones and enhancing the breakdown of hydrocarbons. In this way, rainwater became part of the soil purification process, creating a self-sustaining remediation system (Way, 2013).

For land use, Gas Works Park was transformed into a public green space combining recreation, education, and leisure. It features lawns, walkways, and observation platforms, offering spaces for citizens to relax and host various activities. This project integrates landscape terrain shaping with remediation strategies, using rainwater to aid soil recovery, showcasing an innovative and sustainable long-term design.

Assessment Matrix

The evaluation framework for the remediation section is planned based on the design goals of the site, focusing on two main aspects: facilities and pathways for human activities and habitats for wildlife. To assess the effectiveness of the remediation techniques and plans, there are two primary evaluation standards: human use standards and ecological habitat standards. These standards focus on evaluating the pollution conditions and remediation effectiveness in spaces for human activities and wildlife habitats, respectively.

Additionally, long-term effectiveness and monitoring is an essential component of this evaluation criteria. Through continuous sample collection and monitoring, the smooth implementation of long-term remediation plans can be ensured. This approach also allows for timely adjustments to remediation techniques and plans based on the monitoring results, ensuring continuous improvement.

Ecological Remediation Standards

An evidence-based approach is essential in evaluating remediation techniques in ecological restoration to ensure habitat safety and resilience. Contaminated landscapes, such as former industrial sites, contain pollutants like heavy metals, PAHs, and PCBs that pose serious threats to wildlife. This assessment framework establishes a comprehensive set of measurement metrics to track remediation effectiveness and guide landscape interventions that support species recovery and long-term ecological sustainability.

The framework evaluates multiple remediation strategies across different landscape designs, ensuring they contribute to habitat safety and ecological integrity. There are eight strategies, including sediment capping, soil stabilization, electrokinetic remediation, microbial remediation, phytoremediation, constructed wetlands, stormwater management, and riparian

buffers. To monitor environmental improvements over time, these eight remediation techniques are assessed based on quantifiable metrics, including contaminant reduction, ecosystem health, and functional restoration. Specific metrics evaluate each remediation technique:

1. Sediment capping involves analyzing metal and PCB concentrations in capped sediments to evaluate their effectiveness in containing contaminants in aquatic settings.
2. Soil stabilization aims to determine whether contaminants are locked in place and whether enhancements to soil structure provide stable conditions for plant growth.
3. Electrokinetic remediation focuses on measuring how contaminants move and are extracted using applied electric fields. It assesses the rates of heavy metal migration and the reduction of pollutants.
4. Microbial bioremediation monitors the decrease of PAHs, PCBs, and hydrocarbons while examining the activity of microbial enzymes, reflecting the success of biodegradation processes.
5. Phytoremediation assessments are based on plants' ability to absorb heavy metals and lessen soil toxicity, tracking how well these plants stabilize the contaminants.
6. Constructed wetlands analyze water quality indicators, fish tissue samples, and plant biomass growth to gauge the removal of pollutants and the recovery of ecosystems.
7. Stormwater management is examined by observing the concentrations of heavy metals and PAHs in runoff and evaluating the effectiveness of flood retention systems in mitigating pollutant transport.
8. Riparian buffers are assessed for their effectiveness in preventing soil erosion, enhancing water quality, and supporting healthy vegetation, which stabilizes the landscape and connects habitats.

To align remediation effectiveness with biodiversity goals, these metrics are linked to key indicator species. They are the bald eagle, Canvasback duck, lake sturgeon, monarch butterfly, Eastern fox snake, and Blanding's turtle. This approach ensures that landscape restoration enhances ecological function while maintaining habitat safety.

Remediation Technique	Effectiveness Criteria	Measurement Metrics
Sediment Capping	Reduction in contaminant bioavailability in aquatic habitats	Metal and PCB concentrations in capped sediments
Soil Stabilization	Prevention of contaminant leaching, increased plant establishment	Metal bioavailability tests, soil structure improvement
Electrokinetic Remediation	Mobilization and removal of heavy metals and organic contaminants	Heavy metal migration rates, reduction in PAH/PCB concentrations, electrode efficiency
Microbial Bioremediation	Decomposition of organic pollutants, improved soil, and water quality	Reduction in PAHs, PCBs, and hydrocarbons, microbial enzyme activity
Phytoremediation	Reduction in heavy metal concentration, improved soil health	Metal uptake by plants (Zn, Pb, Cd levels), soil toxicity reduction
Constructed Wetlands	Removal of waterborne pollutants, bioaccumulation prevention, increased plant productivity	Water quality indices (turbidity, metal/PAH levels), fish tissue analysis, plant biomass growth
Stormwater Management	Reduction of runoff contamination, improved hydrological function	Heavy metal and PAH levels in runoff, flood retention effectiveness
Riparian Buffers	Reduction in erosion and contaminant runoff, improved habitat connectivity	Soil erosion rates, water quality indices, vegetation health

Table 14: Criteria for effectiveness and measurement metrics for each remediation technique.

To combine with other matrices for the integrated assessment: 8 indicators. Meeting 0 to $\frac{1}{3}$ (0-2) indicators is the first rung of the scale (1), meeting $\frac{1}{3}$ - $\frac{2}{3}$ (3-5) indicators is the second (2), and meeting $\frac{2}{3}$ - 1 (7-8) indicators is the third (3). This can be adjusted as needed for different scale sizes.

Human Use Standards

Due to the limitations of the academic project design, it is not possible to determine safe exposure based on specific human use standards due to the lack of original contamination data and the current conceptual stage, which makes it difficult to predict the future remediation outcomes. Therefore, the assessment has been divided into four variables to determine whether humans are in a safe exposure state, using binary variables with yes or no answers.

First, the activity area (such as sports fields, museums, and community centers) has a comprehensive short-term and long-term remediation plan. The short-term plan includes techniques like capping and extract and haul to quickly isolate contaminants from people, preventing direct contact and safety risks. The long-term plan includes options for future remediation, such as soil stabilization and microbial bioremediation, after the initial contamination isolation.

Second, the site should have a well-designed road system to guide people to the target areas, ensuring clear pathways. A proper road design also helps prevent people from leaving the trail and entering areas that have not been isolated from contaminants.

Finally, an appropriate buffer zone should be established between the activity/trail areas and the contaminated zones, especially for trails that pass through non-isolated contamination areas. This buffer helps prevent people from stepping into contaminated spaces.

To combine with other matrices for the integrated assessment: 4 indicators. Meeting 0 to $\frac{1}{3}$ (0-1) indicators is the first rung of the scale (1), meeting $\frac{1}{3}$ - $\frac{2}{3}$ (2) indicators is the second (2), and meeting $\frac{2}{3}$ - 1 (3-4) indicators is the third (3).

Long-Term Effectiveness & Monitoring

The main parts of evaluation of remediation include the performance of the technology in terms of its ability to accomplish remediation goals and at what cost, where cost considers economic impact, ecosystem service impact, social impact, and/or human health impact (Gruiz et al., 2019). The best possible way to monitor remediation is through a dynamic monitoring plan, in which data collected during monitoring can inform changes while monitoring is still occurring (Gruiz et al., 2019). Due to the structure of this project, implementing such a plan is not possible by the project team. However, this method of structuring a monitoring plan should be taken into consideration for any remediation actions taken on-site.

The long-term effectiveness of remediation depends on the method selected. More sustainable strategies are not yet well-understood in the long-term (Hou et al., 2023). Some strategies further require a longer time frame to complete remediation or long-term post-remediation risk management (Hou et al., 2023). If a research focus will continue at the project site, then a newer or more sustainable strategy for remediation could be best. This way, research contributing a greater understanding of the efficacy of the strategies could be conducted alongside monitoring of the site.

To balance sustainability, best management practices for green remediation can be employed. From Gruiz et al., (2019), “Green remediation is based on eco-efficiency and is an essential part of sustainability”, and aims to:

- Reduce emissions contributing to climate change;
- integrate adaptive management approach into long-term controls;

- install renewable energy systems to power long-term clean-up and future activities on redeveloped land;
- use passive sampling devices for long-term monitoring where feasible; and
- solicit community involvement to increase public acceptance and awareness of long-term activities and restrictions.

In looking to propose a sustainable future for the project site, the aims of green remediation can be used to assess remediation efforts for this project. Focusing on the long-term impacts of remediation would lead to a focus on the last four bullet points.

They can be considered as categorical nominal variables, where they are either met or not met for the proposed site plans. First, there is a consideration of sampling devices, with a subsequent consideration for passive sampling devices. If there is a plan for sampling devices, then the first criteria will be met, and including passive sampling devices will meet the full criterion. Due to the areas of the project site under consideration, this would likely include soil and groundwater sampling. Based on this, adaptive management can be considered. If the results from sampling do not meet the criteria, as discussed earlier, for ecological or human systems, then additional remediation methods should be employed, or similar adaptive methods. The next consideration is for the energy needed to power any remediation devices. If this does not apply, then there is no need for further consideration, but if it does, then the criteria can be partially met by using some renewable energy to power some of the needs. The criteria can be fully met by using all renewable energy to power remediation methods. Finally, planned efforts for community involvement are crucial, and so having a plan in place for involvement will meet this criteria.

To combine with other matrices for the integrated assessment: 4 indicators. Meeting 0 to $\frac{1}{3}$ (0-1) indicators is the first rung of the scale (1), meeting $\frac{1}{3}$ - $\frac{2}{3}$ (2) indicators is the second (2), and meeting $\frac{2}{3}$ - 1 (3-4) indicators is the third (3).

Evaluation

The assessment matrices, outlined in each variable section above, were applied to the control design and the alternative scenario. The results for each variable are shown below, with an integrated assessment of the two designs following. For the integrated assessment, the different indicators were placed upon a three-point scale, which was noted in the above evaluations.

Carbon Sequestration

For the control scenario, the infiltration basin's area is 80,000 m², equivalent to 8 ha. The total area of various grassland patches is 18,000+28,000+6,000+4,000+700=56,700 m², equivalent to 5.67 ha. Multiplying 478 tC/ha by 8 ha and 8.16 kgC / m² by 56,700 m² will get 3824 tC and 462,672 kgC.

For the alternative scenario, the total areas of wetland, forest, and grassland are 6.828 ha, 14.99 ha, and 383,141 m² (Appendix B). Multiplications will get 3264 tC; 646, 1989, and 100 MgC via vegetation, soil, and litter; and 3,126,431 kgC.

Type	Control	Alternative Scenario
Wetland	3824 tC	3264 tC
Forest	Not applicable	646, 1989, and 100 MgC via vegetation, soil, and litter
Grassland	462,672 kgC	3,126,431 kgC

Table 15: Calculated results of what carbon sequestration potential exists in the control and alternative scenario.

Based on the assessment matrix for carbon discussed above, these two scenarios receive the following scores for three types of ecosystem (Table 16):

Ecosystem Type	Scores	
	Control Scenario	Alternative Scenario
Wetland	3	2
Forest	0	2
Grassland	2	3

Table 16: Scores of three ecosystem types based on carbon sequestration capacities from two scenarios

Energy Generation and Storage

	Control Scenario	Alternative Scenario
Planned Solar Generation (kW)	0	2,367.01
Total Possible Solar Generation (kW)	39,551.90	39,551.90
Percentage of Possible Solar Generation	0%	5.98%
Storage	No	No
Hydropower	No installed turbine	No installed turbine

Table 17: Evaluation of the control and alternative scenario according to the energy assessment matrix.

Solar

The alternatives emphasize solar energy, and as calculated previously, power generation capacity for the area under consideration in this project is 39,551.90 kW. Using the same method, from (1), the generation capacity for the alternative scenario would be 2,367.01 kW, with a total generation area of 49,641.95 m². The alternative scenario would result in 5.98% of the total possible generation capacity, as shown in Table 17. Since there is no solar energy represented in the control, the percentage of the total capacity it represents is 0%.

The small amounts of generation for the control and alternative designs can be explained through the land that energy generation requires. If all of the project site was used for solar generation, then the land would be completely covered with solar panels (if using PV cells). While energy generation can certainly be a part of the project site in the future, it seems likely that the best path forward may not be covering the site with forms of energy generation, like solar panels. Instead, balancing the priorities of the surrounding area, including both human and ecological wants and needs, could be at the forefront of design choices, leading to a trade-off in designs as seen here.

Storage

The control scenario has no storage capacity, and does not meet the criteria for storage, which is also true for the alternative scenario. As was outlined with solar, placing energy storage at this site would limit the other possibilities of use. While energy storage can be a way to advance reliability and access to surrounding communities, if this is not desired, it may not be the best way forward for the site. The value gained from this could be worth it, but to explore other possibilities for the future of the project site in greater detail energy storage is not presented in the designs.

Habitat

Habitat Connectivity and Fragmentation

Bald Eagle.

Parameters	Control Scenario	Alternative Scenario
<i>Functional Connectivity</i>		
Migration path integrity	Poor	Good
Potential barriers	Good	Good
<i>Structural Connectivity</i>		
Distance to nearest habitat	Good	Good
Habitat area within buffer	Medium	Good

Table 18: Results of the assessment for habitat connectivity for the bald eagle.

In terms of functional connectivity, in the control scenario, migration path integrity is rated as poor, indicating that the bald eagles' habitat designed in the control scenario is unable to provide a suitable patch for species resting and nesting, with less connected with surrounding habitats. The alternative scenario shows a good rating, suggesting improved habitat connectivity for migration. Potential barriers, such as roads, bridges, and human disturbances, are considered manageable (good) in both scenarios, meaning they do not significantly impede eagle movement.

In terms of structural connectivity, the distance to the nearest habitat is rated good in the control and alternative scenarios, suggesting improved proximity to suitable nesting or foraging areas. Finally, habitat area within the buffer of the control scenario is medium, but is good for the alternative scenario, ensuring adequate vegetative cover and access to food sources near the river.

Eastern Fox Snake.

Parameters	Control Scenario	Alternative Scenario
<i>Functional Connectivity</i>		
Migration path integrity	Medium	Good
Potential barriers	Medium	Medium
<i>Structural Connectivity</i>		
Distance to nearest habitat	Good	Good
Habitat area within buffer	Medium	Good

Table 19: Results of the assessment for habitat connectivity for the Eastern fox snake.

In terms of functional connectivity, in the control scenario, migration path integrity is rated as medium, indicating the eastern fox snake habitat designed in control scenarios can support species movement path. However, in the alternative scenario, this improves to good, suggesting enhanced habitat connectivity and safer migration routes. Potential barriers, such as roads and urban infrastructure, remain at a medium impact level in both scenarios, indicating ongoing risks but no additional major obstructions.

In terms of structural connectivity, the distance to the nearest suitable habitat is good in both the control scenario and in the alternative scenario. The closest identified habitat to the project site is located at the Detroit River Wildlife Refuge area, which is 1.97 km straight-line distance from our site, suggesting the site has better access to essential habitat features.

Monarch Butterfly.

Parameters	Control Scenario	Alternative Scenario
<i>Functional Connectivity</i>		
Migration path integrity	Poor	Good
Potential barriers	Medium	Medium
<i>Structural Connectivity</i>		
Distance to nearest habitat	Good	Good
Habitat area within buffer	Medium	Good

Table 20: Results of the assessment for habitat connectivity for the monarch butterfly.

In terms of functional connectivity parameters, in the control scenario, the parameter of migration path integrity is poor. This is because the team was unable to identify the specific monarch butterfly's habitat design in the control scenario, and there is a lack of detailed vegetation cover type description. However, in the alternative scenario, the migration path integrity is good. This indicates that the patch in the alternative scenario provides a suitable habitat for monarch butterflies between Humbug Marsh and Grosse Ile, which established a crucial stopover spot for monarch butterflies shortening route across the river. Potential barriers, such as roads and highways, remain at a medium impact level in both scenarios.

In terms of structural connectivity, the distance to the nearest suitable habitat is not applicable in the control scenario, but improves to good in the alternative scenario. The nearest roosting patch of monarch butterflies is at Humbug Marsh, which is 1.65 km straight-distance from the project site. Habitat areas within the buffer are medium in the control scenario but

perform well in the alternative scenario, with more than 50% of the buffer area including some milkweed and nectar sources.

Blanding's Turtle.

Parameters	Control Scenario	Alternative Scenario
<i>Functional Connectivity</i>		
Migration path integrity	Poor	Good
Potential barriers	Poor	Medium
<i>Structural Connectivity</i>		
Distance to nearest habitat	Medium	Medium
Habitat area within buffer	Medium	Good

Table 21: Results of the assessment for habitat connectivity for Blanding's turtle.

In the control scenario, migration path integrity is rated as poor, because there is insufficient wetland design in the control scenario to support Blanding's turtles foraging and feeding. In the alternative scenario, this improves to good, suggesting habitat design in the alternative scenario establishes a wetland for Blanding's turtle that can serve as a stepping stone that connects northern Lake Erie and the St. Clair River delta. Potential barriers, such as roads and human disturbances, are rated poor in the control scenario but improve to medium in the alternative scenario, indicating a reduction in major obstructions but still presenting some challenges.

In terms of structural connectivity, the distance to the nearest suitable habitat remains medium in both scenarios. The nearest wetland habitat of Blanding's turtles is at the Detroit

International Wildlife Refuge, which is about a 1.28 km straight-distance from the site, suggesting that habitat proximity does not change significantly. However, habitat area within the buffer improves from medium in the control scenario to good in the alternative scenario, ensuring better vegetative cover and habitat quality for the species.

Lake Sturgeon.

Parameters	Control Scenario	Alternative Scenario
<i>Functional Connectivity</i>		
Migration path integrity	Poor	Good
Potential barriers	Medium	Medium
<i>Structural Connectivity</i>		
Distance to nearest habitat	Good	Good
Habitat area within buffer	Need more information	Good

Table 22: Results of the assessment for habitat connectivity for lake sturgeon.

In terms of functional connectivity, in the control scenario, migration path integrity is rated as poor, because the basin design is less connected with surrounding water bodies, e.g. Detroit River. This indicates significant obstacles that restrict sturgeon movement between spawning, foraging, and overwintering habitats. In the alternative scenario, this improves to good, suggesting enhanced connectivity, likely through better access to spawning sites and reduced migration barriers. Potential barriers, such as Grosse Ile Parkway Bridge, remain at a medium impact level in both scenarios.

Regarding structural connectivity, both distance to the nearest suitable habitat and habitat

area within the buffer require more information in the control scenario, but in the alternative scenario, both are rated as good, suggesting improved access to key habitats with sufficient space and resources for the species. The corridor designed in the alternative scenario that connects the pond and the Detroit River is 147.13 ft in length, and the length of the channel is approximately 650 m, which is a reasonable distance for lake sturgeon to migrate within home range.

Canvasback Duck.

Parameters	Control Scenario	Alternative Scenario
<i>Functional Connectivity</i>		
Migration path integrity	Poor	Good
Potential barriers	Medium	Medium
<i>Structural Connectivity</i>		
Distance to nearest habitat	Need more information	Good
Habitat area within buffer	Need more information	Good

Table 23: Results of the assessment for habitat connectivity for the Canvasback duck.

Regarding the functional connectivity, in the control scenario, migration path integrity is rated as poor, because the potential habitat pond is less connected with Canvasback ducks' habitats. In the alternative scenario, this improves to good. Wetlands habitat in the alternative scenario provides stepping stones for species movement between the Detroit International Wildlife Refuge and upstream along the Detroit River. Potential barriers, such as shoreline development, remain at a medium impact level in both scenarios.

Regarding structural connectivity, both distance to the nearest suitable habitat and habitat

area within the buffer require more information in the control scenario, but in the alternative scenario, both improve to good, ensuring the presence of sufficient open water, submerged vegetation, and secure resting sites. The nearest habitat of Canvasback ducks is at the Detroit International Wildlife Refuge, which is approximately 1.48 km straight-distance from our site. These results indicate that the alternative scenario significantly enhances migration pathways and habitat availability for Canvasback ducks, supporting their foraging and stopover needs during migration.

Habitat Size and Quality

Six evaluation matrices with varying parameters were used to analyze how each respective species' habitat size and quality requirements aligned with the alternative scenario. The results are presented as tables below, with each table corresponding to one species.

Bald Eagle.

Parameter	Control Scenario	Alternative Scenario
Core Area Size	Poor	Poor
Proximity to Forest	Good	Good
Habitat Structure (Nesting and Perching Trees)	Poor	Good
Proximity to Water	Good	Good
Proximity to Urban Activities	Poor	Medium

Table 24: Evaluation for habitat size and quality for the bald eagle.

For the bald eagle habitat size and quality evaluation, the best suitable options are available in the alternative scenario, with all but two parameters being categorized as “Good”. The only parameter that can be categorized as “Poor” is the Core Area Size, which would also be the same category for the two other scenarios. The bald eagle’s designated habitat size for the alternative scenario is approximately 6.5053 hectares, or 0.065 km², with the requirements for a

“Poor” Core Area Size being below 0.8 km². Proximity to urban areas can be categorized as “Medium” due to the presence of human development nearby (i.e., the new Trenton Channel Power Plant along with other urban areas).

Canvasback Duck.

Parameter	Control Scenario	Alternative Scenario
Pond Availability	Poor	Good
Pond Size	Good	Good
Vegetation Density	Poor	Medium
Disturbance Level	Poor	Good

Table 25: Evaluation for habitat size and quality for the Canvasback duck.

Based on the evaluation matrix for the Canvasback duck habitat, all parameters for the alternative scenario can be categorized as “Good”, save for vegetation density which is categorized as “Medium”. This is due to the vegetation being mostly dominated by grass, and with an emergent vegetation coverage of approximately 23%. The emergent vegetation in this case mainly consists of hardstem bulrush (*Scirpus acutus*), cattails (*Typha* spp.), sedges (*Carex* spp.), Baltic rush (*Juncus balticus*), Pondweed (*Potamogeton pectinatus*), and muskgrass (*Chara* spp.).

Eastern Fox Snake.

Parameter	Control Scenario	Alternative Scenario
Proximity to Wetlands	Good	Good
Proximity to Agricultural Fields	Poor	Good
Proximity to Urban Activities	Poor	Poor
Presence of Edge Habitats	Medium	Good
Vegetation Density and Cover	Poor	Medium
Habitat Connectivity	Poor	Good
Home Range Size (ha)	Good	Good

Table 26: Evaluation for habitat size and quality for the Eastern fox snake.

The Eastern fox snake’s designated habitat for the alternative scenario mostly consists of “Good” categories based on the evaluation matrix, with the exception of the “Proximity to Urban Activities” parameter, with all design scenarios being within 1 km of urban areas (i.e., roads and industrial sites). All habitat scenarios have a close proximity to wetlands, along with an adequate home range size (approximately 29.6 hectares). Vegetation density and cover for the alternative scenario can be categorized as “Medium”, consisting of mainly tree species such as Black Oak (*Quercus velutina*), and emergent plants such as Broadleaf Arrowhead (*Sagittaria latifolia*).

Blanding’s Turtle.

Parameter	Control Scenario	Alternative Scenario
Buffer Zone Size	Poor	Poor
Wetland Availability	Poor	Medium
Habitat Connectivity	Poor	Good
Proximity to Urban Areas	Poor	Poor
Road Density and Crossings	Poor	Medium
Land Cover Composition	Medium	Good
Ephemeral (Temporary) Wetlands Presence	Medium	Good
Human Disturbance Level	Medium	Medium

Table 27: Evaluation for habitat size and quality for Blanding’s turtle

The habitat parameters for the Blanding’s turtle only consists of three “Good” categories: land cover composition, wetlands presence, and habitat connectivity. The habitat itself is located within 1 kilometer of urban areas, in addition to moderately dense roads and crossings, and human disturbance levels. The buffer zone size is also not large enough (below 300 meters), despite having an adequate amount of wetlands for the turtle’s habitat support.

Monarch Butterfly.

Parameter	Control Scenario	Alternative Scenario
Abundance of Milkweed	Poor	Good
Proximity to Urban Activities	Medium	Medium
Floral Diversity	Poor	Medium
Predation Risk	Poor	Poor
Garden Structure	Poor	Medium

Table 28: Evaluation for habitat size and quality for the monarch butterfly.

The habitat for the monarch butterfly in the alternative scenario has a good abundance of milkweed, however, the floral diversity can still be improved upon (only consisting of four

nectar-rich flower species). Garden structure can also be categorized as “Medium”, highlighted by an intermix of both milkweeds and nectar plants. All habitat scenarios also have relatively high predation risks.

Lake Sturgeon.

Parameter	Juvenile Habitat	
	Control Scenario	Alternative Scenario
Water Depth (m)	Poor	Good
Stream Velocity (m/s)	Medium	Medium
Proximity to Urban Activities	Poor	Medium
Substrate Type	Poor	Good
Water Quality	Poor	Good
Sedimentation Level	Poor	Good

Table 29: Evaluation for habitat size and quality for the lake sturgeon’s juvenile habitat.

Parameter	Spawning Habitat	
	Control Scenario	Alternative Scenario
Water Depth (m)	Poor	Good
Stream Velocity (m/s)	Medium	Good
Proximity to Urban Activities	Poor	Medium
Substrate Type	Poor	Good
Water Quality	Poor	Good
Sedimentation Level	Poor	Good

Table 30: Evaluation for habitat size and quality for the lake sturgeon’s spawning habitat.

The lake sturgeon habitat has mostly “Good” categories regarding their listed parameters, with a couple of notable exceptions. Stream velocity can be considered “Medium”, with the Detroit River mean velocity recorded over the last year being 0.78 m/s (U.S. Geological Survey,

n.d.). Overall, there is not much difference between the categories for the juvenile and spawning habitat. Proximity to urban activities can be considered moderate, noting the presence of some human impacts such as the community center (as seen in the alternative scenario).

Habitat Suitability

Species	Habitat Suitability Index	
	Control	Alternative Scenario
Lake Sturgeon	Low	High
Canvasback Duck	Low	High
Eastern Fox Snake	Moderate	High
Bald Eagle	Low	High
Blanding's Turtle	Moderate	High
Monarch Butterfly	Low	High

Table 31: Results from evaluating the alternative scenario and control against the habitat suitability index.

Long-Term Monitoring and Adaptive Management

Evaluation methods. Habitat area and quality is measured by total habitat area, vegetative cover percentage, wetland recovery, and connectivity. For the alternative scenario, the habitat is well-connected, with a high percentage of diverse vegetation cover, ensuring long-term ecological stability. For the control scenario, the total habitat area is relatively smaller, with lower vegetation diversity.

Biodiversity and species population is evaluated based on species richness, population stability, and functional food webs. For the alternative scenario, the habitat design strongly supports the long-term development of biodiversity by providing well-connected environments for key species. For the control scenario, there is no clear design planning for key species habitat.

Contaminant level is assessed by the contaminant removal technologies and long-term

monitoring. For long-term contaminant level monitoring, the alternative scenario and the control scenario all implement appropriate pollution treatment technologies to manage contaminants effectively. These strategies ensure that pollutant levels remain below ecological and human health thresholds, maintaining water and soil quality over time.

Community engagement and aesthetic values are evaluated by the level of public participation, eco-tourism potential, and how well the landscape integrates with urban or rural environments. In the alternative scenario, well-maintained trails, viewing areas, and educational centers are designed to support long-term human connectivity and recreational use while ensuring that tourism activities do not disrupt wildlife or degrade habitat. In the control scenario, there is a lack of the design for human use.

Carbon sequestration and energy usage is measured by carbon storage capacity in wetlands and vegetation, as well as the integration of renewable energy in management operations. The alternative scenario offers a more balanced distribution of carbon sinks across wetlands, forests, and grasslands. The control scenario lags behind, with limited carbon sequestration capacity and lower long-term stability.

Criteria	Control	Alternative Scenario
Habitat area and quality	Medium performance	Good performance
Biodiversity and species population	Medium performance	Good performance
Contaminant level	Good performance	Good performance
Community engagement	Medium performance	Good performance
Carbon sequestration and energy usage	Poor performance	Good performance

Table 32: Results of evaluation of the alternative scenario and control against the matrix for long-term monitoring and adaptive management.

Based on the evaluation results, the alternative scenario demonstrates the strongest overall long-term sustainability, providing well-connected habitats, high biodiversity support, effective contaminant management, strong community engagement, and high carbon sequestration and energy usage. Its balanced ecosystem structure, with wetlands, forests, and grasslands, ensures stable habitat quality, species resilience, and carbon sequestration efficiency over time.

The control scenario shows the weakest long-term ecological performance, with lower habitat area, reduced biodiversity planning, and minimal carbon sequestration potential. While it effectively manages contaminants, the lack of connectivity and human-use design limits both ecological resilience and community benefits.

Human Use

Using the human connectivity assessment matrix, as described above, the control and alternative scenarios were evaluated, with the results displayed below in Table 33.

	Control Scenario	Alternative Scenario
Connection point to Iron Belle and North/South trail	Yes	Yes
Connection point to Elizabeth Park	Yes	Yes
Access point unique to the site for pedestrians, bikers, or other non-vehicle transport	Yes	Yes
Access point for vehicle transport	No	Yes
Amenities not at other parks (tennis)	No	Yes
Amenities not at other parks (pickleball)	No	Yes
Amenities not at other parks (water park or splash pad)	No	Yes
Recreational sport option	No	Yes
Walking/biking option	Yes	Yes
Community gathering space	No	Yes
Proper lighting	Not described	Not described
Spaces to sit	Not described	Yes
Total Indicators Present	4	11

Table 33: Evaluation of the control and alternative scenario against the human use assessment matrix.

As seen in Table 33, the human indicators do considerably better in the alternative than the control design. The control design, as a simple greenway, offers a walking/biking trail for individuals but no other options for human use. The alternative scenario design offers additional ways of accessing the site and amenities beyond a trail, though a trail is still present for individuals who would want to use it. Of course, this is not a guarantee that these scenarios would be the exact layout that would result from real-world community engagement. However, they offer a glimpse into what amenities could be possible at this site, and how it could serve the surrounding community.

As discussed earlier, the main amenities nearby parks lack are tennis courts, pickleball courts, and a splash pad or water park (SEMCOG, 2015). The alternative scenario presented here includes these amenities, which can fill in the gap that was observed. In doing so, the project site can become more than an extension to existing trails or parks as its own space for the community to use and gather at. While it is important to have a connection to the trails of the Downriver Linked Greenways Initiative, or Elizabeth Park, having another access point for the project site helps to ensure individuals are able to use the site regardless of their engagement with the other surrounding parks. The alternative scenario provides this access, and spaces for people to gather at, creating an additional gathering space in addition to what exists at nearby parks.

If true community engagement were to be conducted, it is likely that the inferences that were made with available information of what would be desired for human use for the scenarios would change. Inferences based on demographics, possible stakeholder groups, and other available information was a valuable proxy for the project team. With these inferences, the alternative scenario portrays one way that the surrounding community could engage with the site in the future in more ways than a trail running through the site.

However, it is important to keep in mind that it is not a proper substitute for true community engagement. Perhaps the lack of amenities at nearby parks is not an issue, as these aspects are not demanded by community members. Perhaps there is more demand for additional trails, rather than spaces for sports or a plaza as placed in the alternative scenario. True community engagement to understand these preferences would involve reaching out to community members within Trenton, the neighboring cities, and more broadly in Wayne County, with a focus on the stakeholder groups outlined earlier. While it is possible some, or perhaps all, of the outlined amenities would be desired, it is likely that some change would occur. So, though

the alternative scenario presented here is comparatively better than the control design, it does not mean that it is a perfect representation of what is desired by the community.

Remediation

Long-Term Effectiveness and Monitoring

	Control	Alternative Scenario
Sampling Devices	Not Described	Yes
Passive Sampling Devices	Not Described	Same As Above
Renewable Energy	No	Yes
Community Engagement Plan	Not Described	Not Described
Total	0	3
Result	Poor	Best

Table 34: Evaluation of the alternative scenario and the control for the long-term effectiveness and monitoring criteria.

As shown in Table 34, the alternative scenario performs significantly better than the control. The control design does not account for the placement of any sampling facilities. In contrast, the alternative scenario proposes repurposing the former factory into a museum and constructing an additional research center, where environmental monitoring is integral to their educational and research missions. As a result, sampling devices are essential; however, due to limited technical expertise, no specific distribution plan has been developed. This also leads to meeting the criteria for passive sampling devices. Additionally, the alternative scenario incorporates renewable energy sources, such as solar panels for solar energy and turbines for hydropower, with the collected energy supporting remediation equipment and sampling devices. The community engagement plan is not considered in this academic study.

Ecological Habitat Standards

Since the project, whether in the control design or design scenario phase, is still in the conceptual design stage and has not yet moved to construction, it is not possible to monitor the effectiveness of the remediation techniques upon implementation. At this stage, there can only be assessment based on whether the relevant remediation techniques are included.

	Control	Alternative Scenario
Sediment Capping	No	Yes
Soil Stabilization	No	Yes
Electrokinetic Remediation	No	Yes
Microbial Bioremediation	No	Yes
Phytoremediation	Yes	Yes
Constructed Wetlands	No	Yes
Stormwater Management	Yes	Yes
Riparian Buffers	No	Yes
Total	2	8
Result	Poor	Best

Table 35: Evaluation of the alternative scenario and the control for the ecological habitat criteria.

As shown in Table 35, the alternative scenario performs significantly better than the control design. The control design includes planting strategies such as short-grass-mix, wetland-edge-mix, and plant areas beside trails, which represent simple vegetation distributions that can passively support phytoremediation. Additionally, areas where coal and waste materials were accumulated after the site was abandoned were transformed into an infiltration-basin-mix, a stormwater management feature that helps reduce runoff contamination and improves hydrological function. In the alternative scenario, a more detailed remediation plan is developed

based on the land's intended future use, flexibly applying or combining the eight remediation techniques. Although sample analysis cannot be conducted, the alternative scenario focuses on ecological restoration and habitat creation, featuring larger green spaces and a more detailed ecological remediation plan that considers biodiversity.

Human Use Standards

	Control	Alternative Scenario
The activity area equipped with a comprehensive long-term remediation plan	Not Described	Yes
The activity area using techniques to isolate contaminants from people, such as capping	Not Described	Yes
a well-developed road system connecting the activity areas and the entrances/exits.	Yes	Yes
Buffer zones are established between the activity/trail areas and the contaminated areas	Not Described	Not Described
Total	1	3
Result	Poor	Best

Table 36: Evaluation of the alternative scenario and the control for the human use criteria.

As shown in Table 36, the alternative scenario performs significantly better than the control design. The control design does not include a remediation plan, whereas the alternative scenario contains short-term development and long-term remediation plans that support the site's sustainable development, gradually reducing contaminants to below human use standards. Although the alternative has a well-developed road system, the control design only includes a single path through the park. During idle times, people may exhibit behaviors such as wandering into other areas of the park. In comparison to the alternative scenario, the road system in the control design lacks strong engagement and behavioral constraints, but the evaluation only recorded that the control design has a connected road. Regarding the buffer zone around the

contaminated areas, none of the designs provided detailed information, so it could not be assessed.

Spider Diagrams

The spider diagrams below (Figures 25-31) integrate the evaluation results of all variables and use each variable's assessment matrix to show the scores of two scenarios. This is split based on the six species under consideration, as they each have their own indicators, to make the different indicators in the diagrams easier to understand.

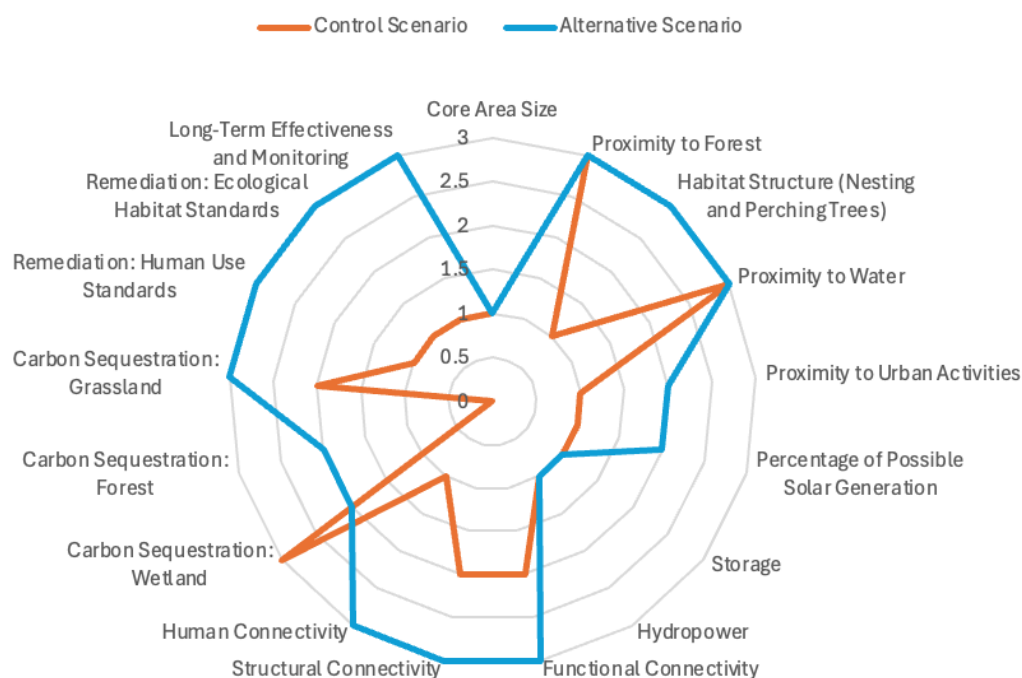


Figure 25: The results of the integrated assessment for parameters considering the bald eagle.

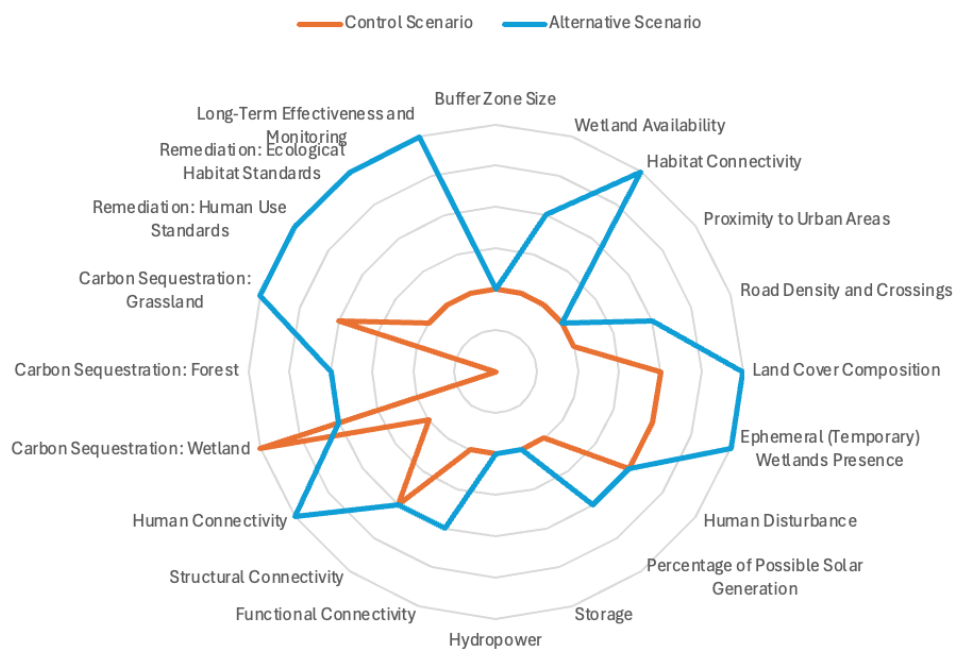


Figure 26: The results of the integrated assessment for parameters considering Blanding's turtle.

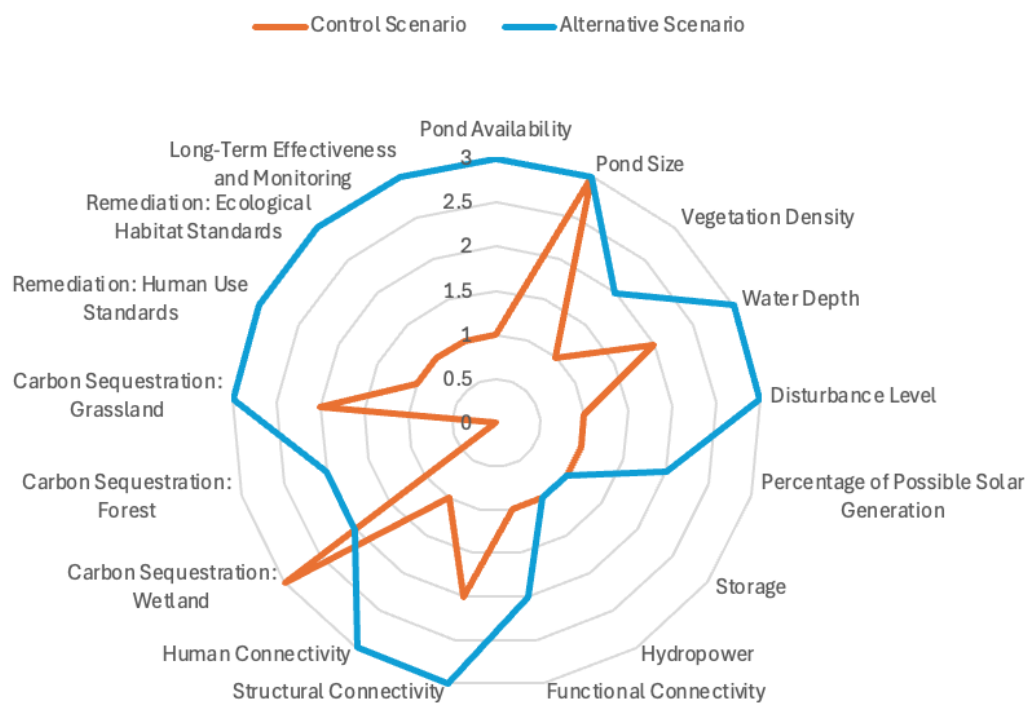


Figure 27: The results of the integrated assessment for parameters considering the Canvasback duck.

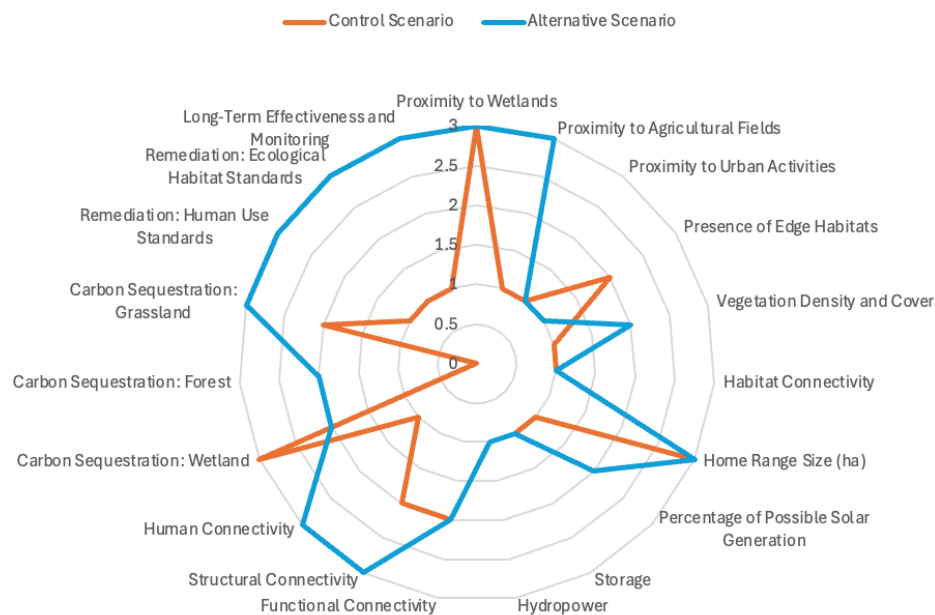


Figure 28: The results of the integrated assessment for parameters considering the Eastern fox snake.

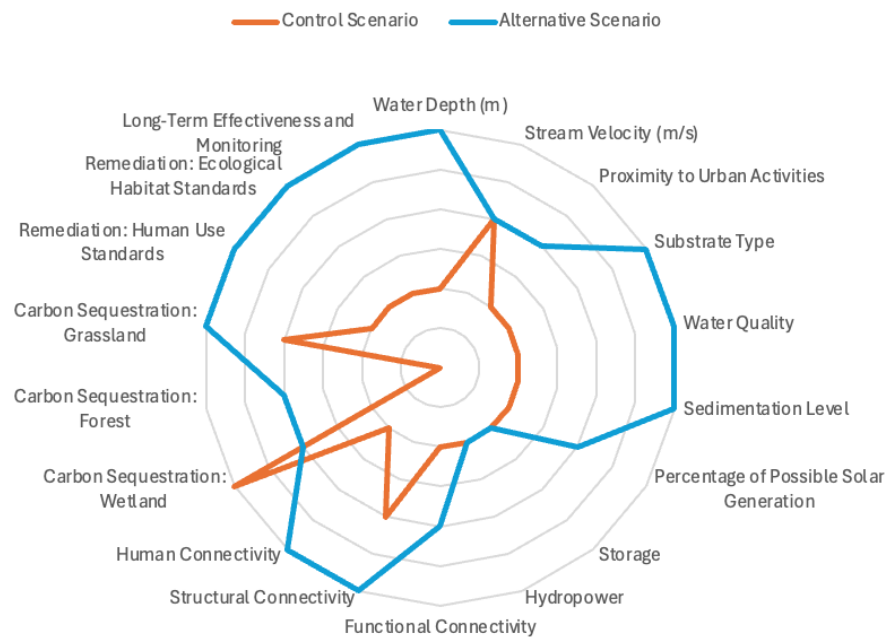


Figure 29: The results of the integrated assessment for parameters considering the juvenile lake sturgeon.

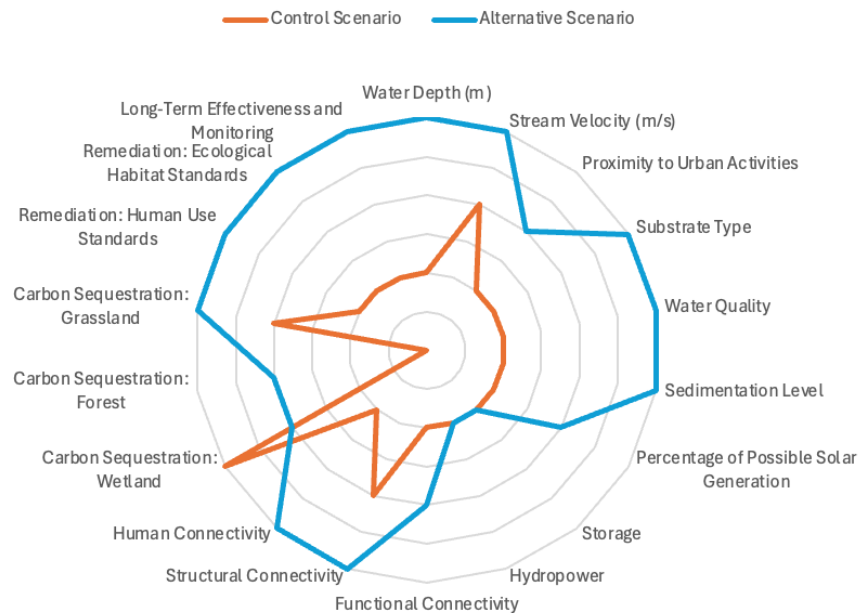


Figure 30: The results of the integrated assessment for parameters considering the spawning lake sturgeon.

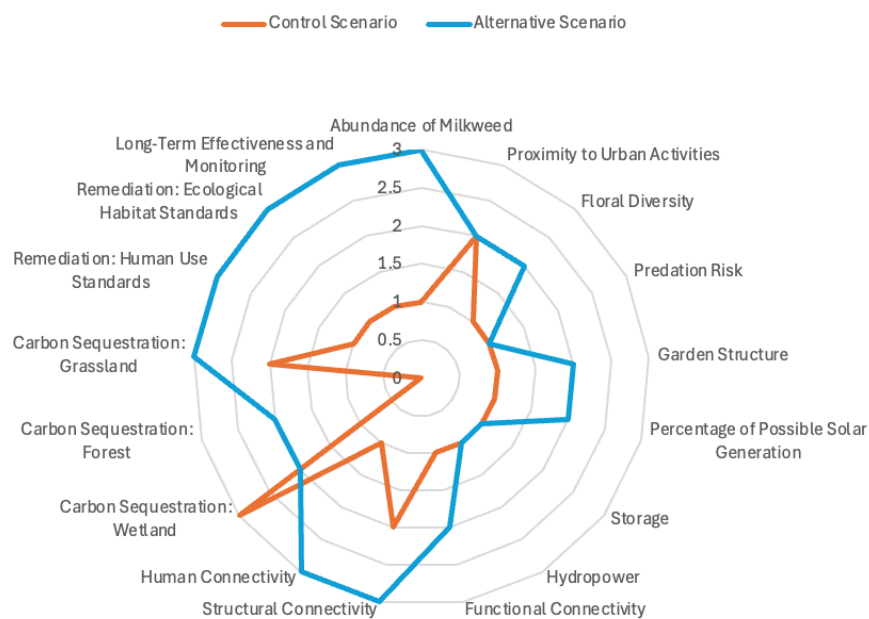


Figure 31: The results of the integrated assessment for parameters considering the monarch butterfly.

The alternative scenario generally does better, for all of the species, than the control when considering remediation, some indicators for carbon sequestration, and human connectivity (Figures 25-31). However, the control scenario does better than the alternative scenario for the wetland indicator for carbon sequestration for all species. For some of the species, the alternative scenario does better on the habitat indicators. However, for the Eastern fox snake, monarch butterfly, the bald eagle, and Blanding's turtle, the difference between the control and alternative scenarios is much smaller. This is interesting, as though the alternative scenario was designed with habitat creation in mind, it is not necessarily the variable with the largest positive difference from the control and alternative scenarios. Additionally, though some of the other indicators for the other variables have some level of trade-off for habitat creation, they still outperform the control. This indicates that even though they do not reach their full potential, the alternative scenario offers a way to meet these indicators that the control does not.

Results

Carbon Sequestration

The carbon sequestration capacity differs between two scenarios because of the differences in the number of ecosystem types and the areas of each ecosystem. The control scenario has a higher wetland carbon storage capacity because of the large infiltration basin. This scenario did not consider forest but designed several grass areas near the trail, so it has a much lower grassland carbon storage capacity than the alternative design. By contrast, the guiding design principle of the alternative design was providing habitat for species and restoring site condition. This scenario has carbon storage from all three ecosystem types and higher grassland storage capacity.

Energy

The control scenario scoring worse on the energy indicators is as expected, as the control design does not consider generating electricity from renewable sources (solar and hydroelectric) or storing energy. The alternative scenario's scoring on the different energy indicators slightly improves when considering the possible percentage of solar energy available on the site, because there are solar panels on existing and proposed buildings. However, the alternative scenario focuses on creating habitats for species conservation and reserving space for human recreational activities, so there is limited land for energy storage facilities and hydroelectric turbines.

Habitat

The variable assessment performed across six different species, each with different parameters regarding their habitat needs, showed that the alternative scenario outperformed the control scenario in nearly each of its variables, which includes habitat connectivity. Based on our calculations, the highest average score of habitat parameters for each species was the lake sturgeon spawning habitat with an average score of 2.5, followed by the Canvasback duck, with an average score of 2.47. This entails that, based on our designated habitat variables specific to each species (including structural and functional connectivity), in addition to carbon sequestration, remediation, and energy storage parameters, our alternative scenario design is best suited for the lake sturgeon and Canvasback duck. It is worth noting, however, that this does not mean that our designs are deemed unsuitable for other species. The lower performance of other species' habitat compared to the two aforementioned species is due to these other species having more "strict" parameters (in the case of the bald eagle, for example, they require a large habitat core size, something that is limited by our design).

Human Use

For human use, the control does worse than the alternative scenario, as seen in Table 33. The dedicated amenities present in the alternative scenario show what could be possible for the project site. Of course, it is entirely possible that with proper community engagement the results would show that perhaps the main desire is a pathway as designed in the control scenario. If this were the case, the matrix would likely change, and the control would outscore the alternative scenario. Given the academic nature of the project, and the inferences drawn from available resources, the alternative scenario offers more amenities and potential for human connectivity than the control design does.

Remediation

Given that the control design and the alternative design all received the same rating in the three assessment matrices for remediation, the final remediation section evaluation results are clear: control design – poor, alternative design scenario – good. However, it is important to note that this result has limitations, as the project is an academic study and is still in the preliminary design phase. The evaluation criteria are simplified to binary judgments, which reduces the precision of the assessment.

Results Discussion

In general, across the variables the control design scores lower than the alternative scenario. It is important to note that the project did not consider other variables, such as cost, which could change the results discussed above. The control design shows one possible future, where a pathway is formed throughout the project site. While it generally scored lower, this does not necessarily indicate that it is a bad design. It does indicate, however, that the design does not fully consider all of the aspects of the variables under study here. To best inform the future of the

project site, as many variables as possible should be considered to see what intersection might exist to move forward with.

Due to the academic nature of the project, a real-world application would need to make use of important considerations that were not fully addressed here. In doing so, the needs of all stakeholders, both human and ecological, can be met and provide a valuable space to the community around the former Trenton Channel Power Plant. As discussed here, that may include an emphasis on the habitat of the six species of concern, the carbon sequestration potential, the energy generation or storage potential, the potential for human connectivity, or the proper remediation. The scenario and research put forward here offers a possible way to do so, but the true future of the site is still yet to be determined.

Conclusion

Carbon Sequestration

This project made an innovative attempt to quantify the carbon sequestration potential of two design scenarios by estimating the carbon storage value of each ecosystem type. This approach can be a reference for other projects at decommissioned fossil fuel power plants that would like to consider carbon sequestration as a variable. However, numerical values used during calculations cannot be directly applied because they are average values for an ecosystem at a certain scale. For example, the value of wetland carbon sequestration is specific to Michigan. This issue also reflects the current knowledge gap of carbon sequestration at individual species level and the potential for more specific carbon calculations in the future.

Energy Generation and Storage

The energy generation and storage techniques considered here show what could be possible for the site of a former power plant. As decommissioning of fossil fuel plants, especially

coal-fired ones, becomes more common, siting renewable energy on them is one way to continue to meet energy demand in a more sustainable way. However, results discussed above show that reserving space for energy generation facilities such as solar panel areas reduces the potential for other uses on the site due to the large amount of needed space. As a result, this energy generation method may be infeasible for sites with multiple needs, but a less demanding technique like the hydropower microturbines installed on water pipes could be a useful method to explore in this context.

This also opens up additional consideration, which was not necessarily possible to consider in this study, for community solar arrays, battery storage, or similar energy generation or storage methods that can be owned by and benefit the surrounding communities. Further community engagement would be needed to successfully plan and execute this, but it is a way for the main benefits of the sites of former power plants, energy, to continue to be seen in neighboring communities without the main drawback of pollution from fossil-fuel based electricity generation.

Habitat

Each species of interest required different variable assessments based on their habitat needs, therefore performing an integrated assessment with all six species at once was unable to be conducted. Nevertheless, our assessments showed that our design was able to accommodate all of our species, with moderate levels of habitat suitability and quality. Some variables that underperformed could still be improved, such as vegetation structure. One variable that could be considered universal is the proximity to human activities and human disturbance levels, which underpins the importance of having undisturbed environments in any habitat restoration projection. Habitats should also accommodate breeding and nesting behavior, thus the

dependency of components such as wetlands and greenery is also a prominent factor.

Connectivity also plays an important role for species to thrive and ensure genetic diversity, hence the importance of corridors that negate any physical boundaries to facilitate migration.

Human Use

This project underscores the importance of early, continuous, and long-term community engagement. Considering aspects like demographics, stakeholder groups, potential recreational amenities that are missing in the area, and environmental justice indicators can provide a starting point, as is done here, for what human communities could desire at these spaces. For this project site, or any other, human desires can only be guessed at without engagement strategies. Without them, the starting design may not represent true community desires. Further, if there is not an effort to engage with the surrounding community beyond the design phase, any resulting site plans may not be used. Community members are more likely to see a space as a community asset if they are involved with it, and so facilitating engagement after the design phase can encourage use and positive relationships with the site.

Remediation

Emerging in-situ remediation techniques such as electrokinetic remediation, phytoremediation, soil stabilization, and microbial bioremediation offer cost-effective long-term pollution treatment. However, their effectiveness is often difficult to predict and monitor. In areas with high contamination levels or direct human interaction, traditional but more expensive methods like extract-and-haul and sediment capping are necessary to enable faster land redevelopment. Highly contaminated soil is removed for off-site treatment, while capping allows human activities aboveground. Small openings can be reserved in capped areas for long-term remediation efforts. Case studies highlight the importance of regular capping inspections, as

external factors over time may cause structural failures, leading to potential exposure and human contact with pollutants.

Beyond human use standards, ecological habitat standards are also crucial. The designated habitat areas should provide a suitable environment and food sources for wildlife, attracting prey species and higher trophic level predators. If contamination is not effectively managed, pollutants may accumulate and magnify through the food chain (plants → herbivores → predators → apex predators), resulting in bioaccumulation and biomagnification. However, habitat areas often coincide with ecosystems such as forests, where extract-and-haul and capping are less feasible, while long-term remediation struggles to address the initial ecological impacts of soil contamination. This remains an unresolved challenge in the current phase of this design research.

Overall Conclusions

With a transition towards clean energy underway in much of the world, sites such as the project location will likely become more common as fossil-fuel generator plants are decommissioned and demolished. This project provides an alternative design for revitalizing a former power plant and meeting desires such as urban green space and habitat creation. The results displayed by spider diagrams show how well all desires are met. In this project, the assessment variables were selected with an idea of what would likely be desired and what could be emphasized, resulting in an alternative scenario that focused on habitat creation. The missing piece, while it should not be leaned upon to provide all of the answers, is some form of community engagement to ensure that any site design does balance desires accurately. Not all sites are the same, and as such different priorities and techniques would likely be used, even if they are similar to the project site.

The scenario approach taken here provides one such way to balance these potentially competing objectives. As the project team aimed to emphasize habitat creation, one might expect that the other variables would fall to the side, and fare similarly to the control scenario. Instead, the indicators for these variables often outperformed the control in the alternative scenario, showing that even with an emphasis on one aspect, the other important considerations can still be thoughtfully included. When balancing these sorts of considerations, different scenarios emphasizing different components can help to fully identify what is a priority. It is possible that the best path forward isn't necessarily a scenario that emphasizes any one desire, but a combination of them.

This project aimed to provide an alternative scenario for the site of the former Trenton Channel Power Plant. As this design was approached from a scenario standpoint, it ultimately focused on habitat creation. Potential futures for the project site may result in a design that features habitat creation for the species under study here. Alternatively, it could lessen the emphasis on habitat creation that a scenario approach gives, with more space allocated to the other variables under consideration here. It is also possible that an entirely different aspect from what was under study here could be decided to be most important, and emphasized for future site use. The future of the project site is still yet to be determined, but this project proposed one possible alternative scenario and evaluated it against the control scenario, highlighting a possible path forward. In doing so, the benefits and drawbacks to these designs are discussed, providing considerations for decision making at the project site and beyond when generalized.

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Appendix A

Alternative Scenario Ecosystem Compositions and their Spatial Allocations

Category	Plant Species
Milkweed Species (Host Plants for Monarchs)	Common Milkweed (<i>Asclepias syriaca</i>)
Milkweed Species (Host Plants for Monarchs)	Swamp Milkweed (<i>Asclepias incarnata</i>)
Milkweed Species (Host Plants for Monarchs)	Butterfly Milkweed (<i>Asclepias tuberosa</i>)
Milkweed Species (Host Plants for Monarchs)	Poke Milkweed (<i>Asclepias exaltata</i>)
Nectar-Rich Wildflowers (Supporting Pollinators)	Wild Bergamot (<i>Monarda fistulosa</i>)
Nectar-Rich Wildflowers (Supporting Pollinators)	Blazing Star (<i>Liatris spp.</i>)
Nectar-Rich Wildflowers (Supporting Pollinators)	Goldenrod (<i>Solidago spp.</i>)
Nectar-Rich Wildflowers (Supporting Pollinators)	Aster (<i>Symphyotrichum spp.</i>)

Table A1: Vegetation species for monarch butterfly

Ecosystem Type	Area (ft ²)
Grassland	433982.45
Forest	0
Total	433,982.45

Table A2: Ecosystem types' size for Monarch Butterfly

Model Natural Community	Category	Plant Species
Lakeplain Oak Openings	Trees	Black Oak (<i>Quercus velutina</i>)
Lakeplain Oak Openings	Trees	White Oak (<i>Quercus alba</i>)
Lakeplain Oak Openings	Trees	Bur Oak (<i>Quercus macrocarpa</i>)
Lakeplain Oak Openings	Trees	Pin Oak (<i>Quercus palustris</i>)
Emergent Marsh	Herbaceous Plants	Broadleaf Arrowhead (<i>Sagittaria latifolia</i>)
Emergent Marsh	Herbaceous Plants	Pickeralweed (<i>Pontederia cordata</i>)
Emergent Marsh	Sedges & Grasses	Lake Sedge (<i>Carex lacustris</i>)
Emergent Marsh	Sedges & Grasses	Bluejoint Grass (<i>Calamagrostis canadensis</i>)

Table A3: Vegetation species and ecosystem types' size for Eastern fox snake

	Area (ft ²)
Constructed wetland-1	463,408.97
Constructed wetland-2	128,308.76
Lakeplain Oak Openings	1,561,298.83
Emergent Marsh	1,040,865.88
Total area	2,602,164.71
Forest Area within Lakeplain Oak Openings	624,519.53
Grassland Area within Lakeplain Oak Openings	936,779.30
Emergent Marsh (Grass)	1,040,865.88
Total area	1,977,645.18

Table A4: Ecosystem types' size for Eastern fox snake.

Category	Plant Species
Riparian Vegetation (Bank Stabilization & Sediment Control)	Willows (<i>Salix spp.</i>)
Riparian Vegetation (Bank Stabilization & Sediment Control)	Sedges (<i>Carex spp.</i>)
Submerged Aquatic Vegetation (Supporting Macroinvertebrate Communities & Water Quality)	Wild Celery (<i>Vallisneria americana</i>)
Submerged Aquatic Vegetation (Supporting Macroinvertebrate Communities & Water Quality)	Common Waterweed (<i>Elodea canadensis</i>)

Table A5: Vegetation species for lake sturgeon

	Area (ft ²)
Wetland-E	104947.3
Riparian buffer	184821
Forest area	92410.5
Grass area	92410.5

Table A6: Ecosystem types' sizes for lake sturgeon

Category	Plant Species
Emergent Vegetation (Nesting and Cover)	Hardstem Bulrush (<i>Scirpus acutus</i>)
Emergent Vegetation (Nesting and Cover)	Cattails (<i>Typha spp.</i>)
Emergent Vegetation (Nesting and Cover)	Sedges (<i>Carex spp.</i>)
Emergent Vegetation (Nesting and Cover)	Baltic Rush (<i>Juncus balticus</i>)
Submerged and Forage Vegetation (Food Sources)	Sago Pondweed (<i>Potamogeton pectinatus</i>)
Submerged and Forage Vegetation (Food Sources)	Muskgrass (<i>Chara spp.</i>)

Table A7: Vegetation Species for Canvasback duck

	Area (ft ²)			Area (ft ²)
Constructed wetland/pond	593880.1		Emergent Marsh	356328.06
Grassland	476180.695		Submerged and Forage Vegetation	237552.04
Forest	476180.695			
Total	1546241.49			

Table A8: Ecosystem Types' Size for Canvasback duck

Model Natural Community	Category	Plant Species
Emergent Marsh	Emergent Vegetation	Cattails (<i>Typha spp.</i>)
Emergent Marsh	Shrubs	Buttonbush (<i>Cephalanthus occidentalis</i>)
Emergent Marsh	Floating Vegetation	Duckweed (<i>Lemna minor</i>)
Emergent Marsh	Grasses	Bluejoint Grass (<i>Calamagrostis canadensis</i>)
Emergent Marsh	Sedges	Lake Sedge (<i>Carex lacustris</i>)
Emergent Marsh	Emergent Vegetation	Broadleaf Arrowhead (<i>Sagittaria latifolia</i>)
Southern Wet Meadow	Sedges	Tussock Sedge (<i>Carex stricta</i>)
Southern Wet Meadow	Wildflowers	Swamp Milkweed (<i>Asclepias incarnata</i>)
Southern Wet Meadow	Wildflowers	Joe-Pye Weed (<i>Eutrochium maculatum</i>)
Southern Wet Meadow	Wildflowers	Marsh Bellflower (<i>Campanula aparinoides</i>)
Southern Wet Meadow	Grasses	Bluejoint Grass (<i>Calamagrostis canadensis</i>)
Dry Sand Prairie	Grasses	Little Bluestem (<i>Schizachyrium scoparium</i>)
Dry Sand Prairie	Grasses	Big Bluestem (<i>Andropogon gerardii</i>)
Dry Sand Prairie	Grasses	Prairie Dropseed (<i>Sporobolus heterolepis</i>)
Dry Sand Prairie	Wildflowers	Wild Lupine (<i>Lupinus perennis</i>)
Dry Sand Prairie	Wildflowers	Hoary Puccoon (<i>Lithospermum canescens</i>)

Table A9: Vegetation Species for Blanding's turtle

	Area (ft ²)
Constructed wetland	125078.4
Emergent Marsh	345,512.94
Southern Wet Meadow	259,134.71
Dry Sand Prairie	259,134.71
Total	988860.76
Emergent Marsh	345,512.94
Southern Wet Meadow	259,134.71
Dry Sand Prairie	259,134.71
Total Grassland area	863,782.36
Forest area	0

Table A10: Ecosystem Types' Size for Blanding's turtle

Category	Plant Species
Canopy Trees for Nesting & Perching	White Pine (<i>Pinus strobus</i>)
Canopy Trees for Nesting & Perching	Red Pine (<i>Pinus resinosa</i>)
Canopy Trees for Nesting & Perching	Aspen (<i>Populus spp.</i>)
Canopy Trees for Nesting & Perching	Yellow Birch (<i>Betula alleghaniensis</i>)
Canopy Trees for Nesting & Perching	Eastern Cottonwood (<i>Populus deltoides</i>)
Canopy Trees for Nesting & Perching	Silver Maple (<i>Acer saccharinum</i>)
Canopy Trees for Nesting & Perching	American Sycamore (<i>Platanus occidentalis</i>)
Canopy Trees for Nesting & Perching	Black Willow (<i>Salix nigra</i>)
Mid-Story & Riparian Buffer Trees	Green Ash (<i>Fraxinus pennsylvanica</i>)
Mid-Story & Riparian Buffer Trees	Red Maple (<i>Acer rubrum</i>)
Mid-Story & Riparian Buffer Trees	Hackberry (<i>Celtis occidentalis</i>)
Shrubs for Riparian Buffers & Nesting Protection	Buttonbush (<i>Cephalanthus occidentalis</i>)
Shrubs for Riparian Buffers & Nesting Protection	Swamp Rose (<i>Rosa palustris</i>)
Shrubs for Riparian Buffers & Nesting Protection	Spicebush (<i>Lindera benzoin</i>)
Additional Vegetation for Hydrological Stability & Ecosystem Health	Riverbank Grape (<i>Vitis riparia</i>)
Additional Vegetation for Hydrological Stability & Ecosystem Health	Silky Dogwood (<i>Cornus amomum</i>)
Additional Vegetation for Hydrological Stability & Ecosystem Health	Common Elderberry (<i>Sambucus canadensis</i>)

Table A11: Vegetation Species for bald eagle

	Area (ft ²)
Forest	420139.692
Grassland	280093.128
Total	700232.82

Table A12: Ecosystem Types' Size for bald eagle

Appendix B

Detailed Information for Calculating Carbon Sequestration Potential of the Alternative Scenario

Species	Forest area needed (square feet)	Grassland area needed (square feet)	Total forest area needed (ha)	Total grassland area needed (m ²)
Monarch butterfly	Not applicable	433,982.45	14.99	383,141
Eastern foxsnake	624,519.53	1,977,645.18		
Lake sturgeon	92,410.5	92,410.5		
Canvasback duck	476,180.695	476,180.695		
Blanding's turtle	Not applicable	863,782.36		
Bald eagle	420,139.692	280,093.128		

Appendix C

Bioenergy Site Analysis

There are large areas of uncertainty surrounding using biomass from contaminated sites for bioenergy production. The additional cost of separating pollutants may provide a disincentive for prioritizing biomass use on the site. An additional factor against biomass use at this site is that the nearest combustion biomass plant, which uses wood/wood waste, is in Archbold, OH (*Sauder Power Plant*, n.d.). This is about 90 miles from the project site (Google, n.d.). It seems likely that the emissions of transporting any biomass to this plant would counteract any emissions reductions from using it for energy generation instead of fossil fuels. Transportation might also cost more than what the biomass is worth, further limiting benefits from its use.

Given the additional cost of separating out pollutants and transportation, biomass is a less viable option for renewable energy generation at this site. When considering what to plant, it would presumably be better to use a plant more suited to phytoremediation than one that can be used for biomass production and phytoremediation. Thus, an alternative scenario for the project site should not consider biomass as an energy generation method.

Bioenergy Literature Review

Bioenergy is “a form of energy that is derived from recently living organic materials known as biomass” (*Bioenergy Basics*, n.d.). Most commonly, this means biomass is combusted, which can be cost-competitive with fossil fuel alternatives (Bauen et al., 2009). If a site is being considered to grow crops for bioenergy, existing land uses and past contamination for a site should be taken into consideration. Studies suggest *Miscanthus* species, a common crop used for bioenergy, have the ability to persist on contaminated sites, but with very high concentration of pollutants there may be less biomass production (Pandey et al., 2016). While this is only one example, it shows that past contamination can limit the maximum theoretical yield of a site.

Biomass crops could also play a role in phytoremediation, where the crops in question would be taking up contaminants at a site. The additional benefit of phytoremediation could mitigate the impact of a lower biomass yield for bioenergy. Any possible combustion would include the contaminants, unless they are removed from the dried biomass. Methods do exist for removing the pollutants from the biomass prior to energy generation (Pandey et al., 2016). However, the fate of pollutant-containing biomass harvested after phytoremediation is largely unstudied, and research or management studies for biomass-produced post-remediation are limited (Khan et al., 2023). There is proof of concept for recovery of nickel with dried biomass used for phytoremediation, but is unproven for other heavy metals (Khan et al., 2023). Given the uncertain nature of using biomass that has been used for phytoremediation for bioenergy, more research is needed, which could be a future use for this project site.

Appendix D

Habitat Connectivity Assessment Framework Tables

Parameters	Good Condition	Medium Condition	Poor Condition
Functional Connectivity			
Migration path integrity	The site can serve as a corridor between wetlands (foraging) and uplands (hibernation)	The habitat in site is a patchy habitat connectivity, requiring longer or riskier travel routes.	The habitat in site is unable to connect with suitable upland hibernation sites, forcing snakes into unsuitable areas.
Potential physical boundaries	No boundaries (e.g. roads, streets) between different habitat patches.	1-2 physical boundaries (e.g. roads, streets) or existing vegetation shelter shortage that partially impact movement.	>3 physical boundaries are impermeable, resulting in road mortality.
Structural Connectivity			
Distance to Nearest Patch	Distance to nearest patch < 2km	Distance to nearest patch between 2 km to 5 km	Distance to nearest patch > 5 km
Habitat Area Within Buffer	>70% of the habitats on the main migration routes are suitable	40-70% of the habitats on the main migration routes are suitable	<40% of the habitats on the main migration routes are suitable

Table D1: The Eastern fox snake's habitat connectivity assessment framework (Lee, Y. 2000; Robison, 2016)

Parameters	Good Condition	Medium Condition	Poor Condition
Functional Connectivity			
Migration path integrity	The site's vegetation cover provides adequate nectar-rich plants, and stepping stones exist between patches.	Partially nectar-rich plants in the site, and stepping stones exist between patches.	Lack or insufficient nectar-rich plants along in the site, and lack of corridor for species movement.
Potential physical boundaries	No significant barriers; open landscapes with continuous nectar corridors and milkweed patches	1-2 physical barriers, such as moderate road networks, urban expansion, or scattered habitat patches	>3 physical barriers, such as highways, urban areas, large agricultural fields, or deforested land, disrupting Monarch movement
Structural Connectivity			
Distance to Nearest Patch	Distance to nearest patch < 5km	Distance to nearest patch between 5 km to 10 km	Distance to nearest patch > 10 km
Habitat Area Within Buffer	>70% of the buffer area consists of native milkweed species and abundant nectar plants in meadows, prairies, or open fields	40–70% of the buffer area includes some milkweed and nectar sources, but fragmented or moderately disturbed	<40% of the buffer area consists of suitable nectar plants or milkweed, with severe habitat loss

Table D2: The monarch butterfly's habitat connectivity assessment framework (Pleasants, J. M. 2017; Craves, J. A. 2008)

Parameters	Good Condition	Medium Condition	Poor Condition
Functional Connectivity			
Migration path integrity	Adequate well-established and continuous wetland in the site.	Partially well-established and continuous wetland in the site.	Lack of insufficient wetland in the site.
Potential physical boundaries	No boundaries (e.g. roads, streets) between different habitat patches.	1-2 physical boundaries (e.g. roads, streets) or unbalancing vegetarian cover of aquatic and terrestrial habitat, resulting in movement restricted.	>3 physical barriers severely hinder species migration. And heavily unbalancing habitat vegetation type.
Structural Connectivity			
Distance to Nearest Habitat	Distance to nearest wetland < 1km	Distance to nearest wetland between 1 km to 5 km	Distance to nearest wetland > 5 km
Habitat Area Within Buffer	>70% of the buffer area consists of interconnected wetlands, marshes, and slow-moving water with adjacent upland nesting sites	40–70% of the buffer area includes some wetland habitat, but with moderate fragmentation or limited nesting areas	<40% of the buffer area includes suitable wetlands or nesting areas, with severe habitat loss or degradation

Table D3: Blanding's turtle's habitat connectivity assessment framework (Lee, Y. 1999; Derosier, A.L., 2015)

Parameters	Good Condition	Medium Condition	Poor Condition
Functional Connectivity			
Migration path integrity	Continuous water body in the site, and provide channels to connect with surrounding lakes or rivers.	Partially continuous waterbody in the site. And partially connected with surrounding water bodies.	Lack of an insufficient waterbody in the site and habitat patch is isolated.
Potential physical boundaries	No blocks and human activity disturbance around water bodies in the site.	1-2 mild physical barriers that partially hinder movement but do not completely prevent migration between water bodies (e.g., dams, bridges, marina).	>3 physical barriers that make water bodies fragmented and isolated.
Structural Connectivity			
Distance to Nearest Habitat	Distance to nearest water body < 5km	Distance to nearest water body between 5 km to 10 km	Distance to nearest water body > 10 km
Habitat Area Within Buffer	>70% of the buffer area consists of deep water habitats (≥ 5 m depth), rocky or gravel spawning sites, and clean, well-oxygenated water	40–70% of the buffer area includes deep water, but with some habitat degradation or fragmentation	<40% of the buffer area includes suitable spawning or foraging habitat, with significant degradation

Table D4: The lake sturgeon's habitat connectivity assessment framework (Galarowicz, 2003; Elizabeth M. Hay-Chmielewski, 1997)

Parameters	Good Condition	Medium Condition	Poor Condition
Functional Connectivity			
Migration path integrity	Wetlands habitat in the site provides stepping stones for species movement between habitats.	Wetlands habitat in the site partially provides stepping stones for species movement between habitats.	Isolated wetlands or insufficient wetlands within the site.
Potential physical boundaries	No blocks and human activity disturbance around the wetland.	1-2 mild physical barriers that partially hinder movement but do not completely prevent migration between wetlands.	>3 physical barriers that are impermeable to cross and heavy human disturbance around wetland .
Structural Connectivity			
Distance to Nearest Habitat	Distance to nearest water body < 5km	Distance to nearest water body between 5 km to 10 km	Distance to nearest water body > 10 km
Habitat Area Within Buffer	>70% of the buffer area consists of shallow wetlands, marshes, or open water with abundant submerged aquatic vegetation.	40–70% of the buffer area includes wetland patches, shallow water, or moderate vegetation	<40% of the buffer area consists of suitable wetlands, with significant habitat loss or degradation

Table D5: The Canvasback duck's habitat connectivity assessment framework (Mowbray, T. B., 2020; Hartig, 2022)

Appendix E

Parameter	Good	Medium	Poor
Pond Availability	Semi-permanent or permanent ponds, available throughout the nesting and foraging season.	Seasonal ponds, available during most of the breeding season but prone to drying in drought years.	Temporary ponds, unreliable, often dry before the nesting season ends.
Pond Size	5+ hectares, providing sufficient open water and vegetation interspersion.	1–5 hectares, adequate for nesting but may limit foraging area.	<1 hectare, too small to support stable populations.
Vegetation Density	>50% emergent vegetation (cattails, bulrushes, willows), providing optimal nesting cover.	10–50% emergent vegetation, moderate cover but some risk of predation.	<10% emergent vegetation, limited concealment and higher predation risk.
Water Depth	1–2 meters, ideal for diving and foraging on submerged vegetation.	0.5–1 meter, sufficient for foraging but less protection from predators.	<0.5 meters, too shallow for diving ducks, increased risk of drying.
Disturbance Level	<10% of the habitat affected by human or livestock activity (e.g., minimal grazing, no significant habitat loss).	10–50% of the habitat affected, moderate human/livestock presence but nesting still possible.	>50% of the habitat affected, high levels of disturbance, reducing nesting success.

Table E1: The parameters that would be most suitable to assess the habitat of a Canvasback duck, both in terms of habitat (patch) size and quality (Zdan, 1979; Soulliere et al., 2007; Krasowski & Nudds, 1986; Johnson & Grier, 1988).

Parameter	Good	Medium	Poor
Proximity to Wetlands	Close (<500m) to wetlands or marshes	Moderate distance (500m-1.5km) from wetlands	Far (>1.5km) from wetlands or absent
Proximity to Agricultural Fields	Far (>2km) from agricultural fields	Moderate distance (1-2km) from agricultural fields	Close (<1km) to agricultural fields
Proximity to Urban Activities	Far (>3km) from urban areas	Moderate distance (1-3km) from urban areas	Close (<1km) to urban areas
Presence of Edge Habitats	High presence of edge habitats (upland, forest, wetland)	Some edge habitats but fragmented	Few or no edge habitats
Vegetation Density and Cover	Dense herbaceous vegetation, logs, and debris piles	Moderate vegetation density, some cover but patchy	Sparse vegetation cover, little hiding space
Habitat Connectivity	Strong connectivity between habitats (corridors available)	Some connectivity but barriers present (e.g., roads)	Highly fragmented, isolated habitat patches
Home Range Size (ha)	Moderate to large (20-54 ha) with well-distributed resources	Small to moderate (10-20 ha) with some fragmentation	Very small (<10 ha), highly fragmented with poor resources

Table E2: The parameters that would be most suitable to assess the habitat of the Eastern fox snake, both in terms of habitat (patch) size and quality (Shew et al., 2012; DeGregorio et al., 2011; Watson, 1995).

Parameter	Good	Medium	Poor
Buffer Zone Size	≥600m buffer around wetlands	300-600m buffer	<300m buffer
Wetland Availability	High number of interconnected lakes, permanent, and ephemeral wetlands	Moderate number of wetlands, some fragmentation	Few wetlands, highly fragmented
Proximity to Urban Areas	Far from urban areas (>5 km)	Near small towns (1-5 km)	Adjacent to urban or industrial areas (<1 km)
Road Density and Crossings	Low road density, no major crossings	Moderate road density, occasional crossings	High road density, frequent crossings
Land Cover Composition	High proportion of wetlands and forests, low agriculture/urban	Balanced mix of wetlands, forests, and agriculture	Dominated by agriculture, urban, or industrial areas
Ephemeral (Temporary) Wetlands Presence	Ephemeral wetlands well-distributed, accessible	Few ephemeral wetlands, limited accessibility	Ephemeral wetlands absent or degraded
Human Disturbance Level	Minimal human disturbance, protected areas	Some human disturbance, managed lands	High human activity, unprotected lands

Table E3: The parameters that would be most suitable to assess the habitat of the Blanding's turtle, both in terms of habitat (patch) size and quality (Refsnider & Linck, 2012; Fortin et al., 2015).

Parameter	Good	Medium	Poor
Abundance of Milkweed	High density (≥ 10 milkweed plants per 10m^2)	Moderate density (5-9 milkweed plants per 10m^2)	Low density (< 5 milkweed plants per 10m^2)
Proximity to Urban Activities	Low (natural or protected areas)	Moderate (suburban gardens, some human activity)	High (urban core, industrial areas)
Floral Diversity	High (multiple nectar species blooming all seasons)	Moderate (some seasonal nectar sources)	Low (few or no nectar sources)
Predation Risk	Low (minimal predators, good habitat structure)	Moderate (some predators present)	High (frequent predation events)
Garden Structure	Structured (milkweed on perimeter, well-spaced)	Mixed structure (milkweed and nectar plants intermixed)	Random structure (milkweed scattered, poorly spaced)

Table E4: The parameters that would be most suitable to assess the habitat of the Monarch Butterfly, both in terms of habitat (patch) size and quality (Fisher & Bradbury, 2023; Baker & Potter, 2019).

Juvenile Habitat			
Parameter	Good	Medium	Poor
Water Depth (m)	2.0 - 7.9	0.5 - 1.9 or 8.0 - 14.0	<0.5 or >14.0
Stream Velocity (m/s)	0.1 - 0.5	0.6 - 1.0	>1.0
Proximity to Urban Activities	Low (Minimal Human Impact)	Moderate (Some Human Impact)	High (Industrial, Heavy Urban)
Substrate Type	Silt, Sand, Gravel	Mixed Substrates (Sand & Gravel)	Bedrock, Clay, Artificial
Water Quality	High (Clean, Low Contaminants)	Moderate (Some Contaminants)	Low (High Pollution, Poor O ₂)
Sedimentation Level	Low (Clear Substrate)	Moderate (Some Sediment)	High (Silt Covers Habitat)

Table E5: The parameters that would be most suitable to assess the juvenile habitat of the lake sturgeon, based on the quality of the habitat (Fisheries Division DNR, 1997; Baril et al., 2017; Ontario Ministry of Natural Resources, 2011; Daugherty et al., 2011; Bennion & Manny, 2014).

Spawning Habitat			
Parameter	Good	Medium	Poor
Water Depth (m)	0.6 - 5.0	5.1 - 10.0	<0.6 or >10.0
Stream Velocity (m/s)	0.5 - 2.5	0.3 - 0.5	<0.3 or >2.5
Proximity to Urban Activities	Low (Minimal Human Impact)	Moderate (Some Human Impact)	High (Industrial, Heavy Urban)
Substrate Type	Cobble, Boulder, Gravel	Mixed Substrates (Gravel & Sand)	Clay, Silt, Bedrock
Water Quality	High (Clean, Low Contaminants)	Moderate (Some Contaminants)	Low (High Pollution, Poor O ₂)
Sedimentation Level	Low (Clear Substrate)	Moderate (Some Sediment)	High (Silt Covers Habitat)

Table E6: The parameters that would be most suitable to assess the spawning habitat of the lake sturgeon, based on the quality of the habitat (Fisheries Division DNR, 1997; Baril et al., 2017; Ontario Ministry of Natural Resources, 2011; Daugherty et al., 2011; Bennion & Manny, 2014).