A Framework for Comprehensive, Site-Specific Remediation of Polychlorinated Biphenyl (PCB) Contamination in Pittsfield, Massachusetts

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Clem Doucette

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Thesis Advisor: Jon Witten

Thesis Reader: Scott Horsley

ABSTRACT

Polychlorinated biphenyls (PCBs) are a group of manmade organic chemicals known for their detrimental effects to human and environmental health. PCBs were widely used as an oil-based insulation medium for power transformers before the Toxic Substances Control Act of 1976 (TSCA) outlawed their manufacture and use in the United States. Pittsfield, Massachusetts, a medium-sized city with significant environmental justice populations, was the location of a General Electric transformer plant that handled large quantities of PCBs between 1932 and 1977. Throughout the manufacturing period, widespread PCB contamination occurred on land and groundwater adjacent to the plant, in addition to much of the Housatonic River. An extensive remediation effort began in the 1990s to decontaminate numerous affected sites in the Pittsfield area, and remediation continues to the present day. However, this remediation is far from complete and area residents and activists remain concerned about the presence of contaminated soil and groundwater in the city.

This thesis analyzes existing literature to pinpoint the locations, extent, and remediation statuses of contaminated locations throughout the city, in addition to deficiencies in the implemented remediation strategies. Furthermore, this work reviews several novel low-impact *in-situ* (on-site) PCB remediation best management practices that differ from the traditional and potentially harmful methods of on-site containment, dredging, or off-site containment and disposal of contaminated materials. Findings from this review indicate that there are at least three sites where further remediation activity is warranted; this work provides specific recommendations for two of these sites using low-impact, *in-situ* remediation methods.

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Lastly, I would like to dedicate this work to my late grandfather, Lionel Doucette, a longtime Lakewood resident, a 37-year employee of the General Electric Pittsfield Plant, and an endless source of inspiration for me.

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GLOSSARY OF FREQUENTLY USED TERMS AND ABBREVIATIONS

Abbreviation	Definition
AFY	Acre-feet per year
ARPA	American Rescue Plan Act (2021)
ATSDR	Agency for Toxic Substances and Disease Registry
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (1980)
DNAPL	Dense Non-aqueous Phase Liquid
DPH	Massachusetts Department of Public Health
Ex-situ	Offsite/not-in-place
GAC	Granular Activated Carbon
GE	General Electric Company
HRI	Housatonic River Initiative
In-situ	Onsite/in-place
LNAPL	Light Non-aqueous Phase Liquid
MassDEP	Massachusetts Department of Environmental Protection
NPDES	National Pollutant Discharge Elimination System
OH-PCB	Mono-hydroxylated Polychlorinated Biphenyl
OPCA	On-Plant Consolidation Area
PAC	Powdered Activated Carbon
PCB	Polychlorinated Biphenyl
ppm	Parts per million
RAA	Removal Action Area
TMDL	Total Maximum Daily Load
TSCA	Toxic Substances Control Act (1976)
USDA	United States Department of Agriculture
USGS	United States Geological Survey
US EPA	United States Environmental Protection Agency

INTRODUCTION

Pittsfield, Massachusetts is the largest city in Berkshire County and a former hub for General Electric's power transformer manufacturing operations. For eighty-four years, from 1903 until October 1987, the General Electric Pittsfield Plant served as the economic life source for Pittsfield and much of Berkshire County.[1] Following the downsizing and eventual closure of the transformer plant, Pittsfield experienced a rapid process of deindustrialization and is now classified as one of Massachusetts' 26 "Gateway Cities[a]."[2] While the closure of the General Electric plant left behind a legacy of economic decline and long-term restructuring in Pittsfield,[3] decades of transformer manufacturing in the city resulted in an even greater long-term impact: the widespread contamination of Pittsfield's soils and groundwater, in addition to much of the Housatonic River watershed, with polychlorinated biphenyls (PCBs).[4]

PCBs are highly carcinogenic organic chlorine compounds classified as persistent organic pollutants by the United States Environmental Protection Agency and the Stockholm Convention on Persistent Organic Pollutants, meaning that are largely resistant to degradation by biological, chemical, or photolytic processes.[5] Once released into the environment, PCBs remain in soils and waterbodies for decades and can be transported long distances due to their strong binds with soils and sediments.[6] Consequently, the manufacturing of PCBs has been banned in the United States since 1977 and internationally since 2001.[7]

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[a] Designated midsize urban centers in Massachusetts that anchor regional economies. Most "Gateway Cities" were once home to manufacturing jobs which have since disappeared.[2]

History of PCBs and Awareness of Impacts

Commercial production of PCBs began in 1929 at the Swann Chemical Company and was taken over by the Monsanto Chemical Company in 1935.[8] The adverse health and environmental impacts of PCB exposure and contamination are long-understood and well-documented. In the mid-1930s, the toxicity of PCBs became apparent after a series of industrial accidents that resulted in exposed workers developing severe acne and dermatitis. In a 1936 incident at the Bakelite Corporation, there were three “fatal cases of jaundice”[b] in workers who had been exposed to PCBs and chlorinated naphthalenes.[9] In 1937, the Harvard School of Public Health urgently organized a conference to assess the hazards of PCBs, which resulted in several publications.[10] Through the mid-twentieth century, scientists became increasingly aware of the dangers of PCB exposure, including chemists at the Monsanto Chemical Company; however, Monsanto continued to manufacture the compounds despite being aware of their dangers. A 2002 leak of Monsanto documents revealed that the corporation had willfully concealed knowledge that their PCB-containing compounds were likely carcinogenic and had led to widespread contamination of waterbodies and aquatic organisms.[11]

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[b] The “fatal cases of jaundice” were likely instances of acute liver failure induced by the hepatotoxicity of PCB compounds.[193]

Impacts on Human and Environmental Health

Among PCB-containing compounds, toxicity severity varies based on the chemical structure of the compound. Coplanar[c] PCB congeners are of most concern to regulatory bodies due to their high toxicity and long half-life.[12] In terms of environmental and health impacts, coplanar PCBs are similar to polychlorinated dibenzo-*p*-dioxins (PCDDs, commonly, yet inaccurately, referred to as "dioxins" in regulatory literature).[d] As a result, coplanar PCBs are often grouped with dioxin and dioxin-like compounds when assessing environmental and human impacts.[12]

Exposure to PCBs, especially coplanar PCB congeners, is associated with wide-ranging detrimental effects to human health.[9, 12, 13, 14] Exposure generally occurs through direct large-scale exposure to PCBs from industrial applications, consuming PCB-contaminated food, inhaling contaminated air, and skin contact. Once in the bodies of humans and other aquatic and terrestrial organisms, PCBs have a half-life of 10-15 years, they can biomagnify[e], and may be passed on to offspring through breast milk.[13]

The most common effects of high- PCB exposure observed are chloracne and rashes, which are symptoms of systemic poisoning.[9, 14] In Japan in 1968, PCB contaminated chicken feed led to a mass poisoning incident termed "Yushō Disease."[14] Those afflicted suffered from a wide range of symptoms including dermal and ocular lesions, irregular menstrual cycles, lowered immune responses, fatigue, and cough.[14]

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[c] 12 of the 209 possible PCB molecules that do not have a chlorine atom in the "ortho" (number 2 or 6) position. Only four of these twelve coplanar PCB molecules are generally present in commercial mixtures.[194]

[d] Coplanar PCBs are "dioxin-like" because they bind to the same biological receptor protein as dioxin, polycyclic aromatic hydrocarbons (PAHs), and a variety of other environmental pollutants.[194]

[e] Also known as bioamplification or biological magnification. This refers to the increase in concentration of a substance in the tissues of organisms at increasingly higher levels of a given food chain.[85]

Among children, there were reports of decreased cognitive development.[14] As previously mentioned, changes to blood and urine that are indicative of liver damage have also been observed in industrial workers directly exposed to PCBs.[9] PCB poisoning is also associated with mutagenic (cell-mutating) effects by interfering with hormones in the human body.[15] Coplanar PCB congener poisoning may both inhibit and imitate estradiol; imitation of estradiol can feed estrogen-dependent breast cancer cells and lead to cervical or uterine cancers.[15] In males, estradiol inhibition is associated with sexual, skeletal, and cognitive development disorders.[15]

General Electric's Use and Disposal of PCBs in Pittsfield

In Pittsfield, the primary PCB-containing compound responsible for widespread contamination is Pyranol transformer oil, comprised largely of Aroclor-1254 and Aroclor-1260.[16] Aroclor-1248 was also likely used at the General Electric transformer plant.[17] These compounds are trademarked coplanar PCB-containing transformer oils that were used from circa 1932 until 1977.[7, 8, 16] Because of their high dielectric strength, inflammability, and insulating properties, PCBs were widely used to produce insulating transformer oil.[18] PCB containing compounds and transformer oils were manufactured and trademarked by several firms; Pyranol was developed by General Electric and Monsanto in the 1930s for use in General Electric's proprietary transformers, while Aroclor branded compounds were manufactured and sold exclusively by Monsanto.[16]

Throughout the 45-year manufacturing period in which PCBs were legal, General Electric disposed of PCB-containing waste in the Housatonic River and adjacent areas.[4] Goodrich Pond and Silver Lake are two waterbodies into which PCBs were directly disposed or became contaminated, while the area of the current Brattle Brook Park conservation area once served as a dumping site for PCB contaminated material.[19] The exact amount of PCB waste disposed of in Pittsfield and the Housatonic River watershed is difficult to accurately determine.[19] In December 1982, Stewart Laboratories performed a study of PCB contamination in the Housatonic River under the direction of General Electric.[20] The study estimated that a total of 40,000 pounds and 250,000 cubic yards of PCBs were contained in Housatonic River sediments in Massachusetts.[20] 70% of the contaminated sediment was situated between the former plant in Pittsfield and Woods Pond Dam in Lee; 20% in Woods Pond itself, and the remaining 10% between Woods Pond Dam and the Connecticut border.[20] Despite the bias inherent to this study, the United States Environmental Protection Agency accepted Stewart Laboratories and General Electric's findings and analysis.[19]

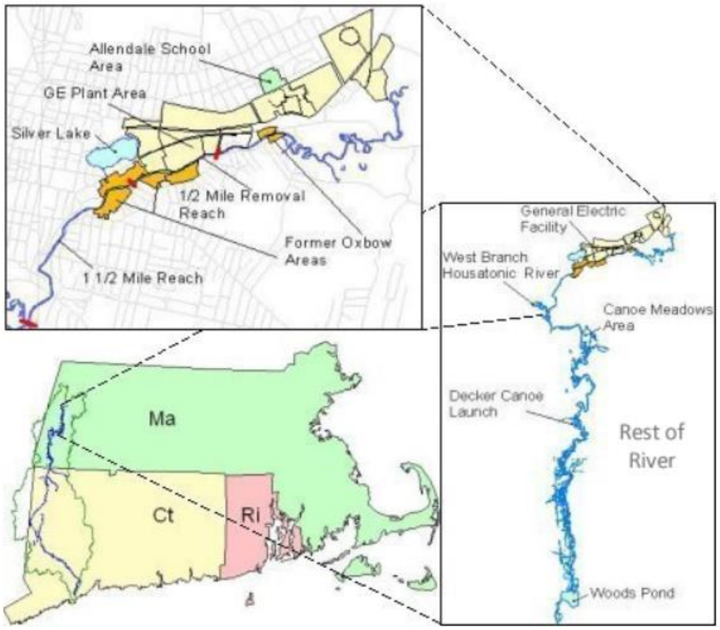


Figure 1: Locus map of the Housatonic River and cleanup sites. Source: United States Environmental Protection Agency.

Interviews with General Electric employees involved in quality control and management of transformer oil and transformer manufacturing, as well as with Pittsfield elected officials and residents, suggest that the actual amount of PCB contamination in soils and river sediments is higher than this 1982 study suggests.[21, 22] In 1990 the Housatonic River Initiative interviewed Ed Bates, the former manager of the Power Transformers sub-section of the General Electric plant.[21] Bates reported that the plant handled 20,000 gallons or 140,000 pounds of Pyranol per week at a spillage rate of approximately 3%, meaning that "every week [they] would lose between 4,000 and 5,000 pounds of PCBs that would go down the drain and into the river."[21]

In the 1970s and early 1980s, reports emerged of an "underground lake" of PCB compounds located in the vicinity of the General Electric plant, caused by the sheer volume of leaked and dumped transformer oil.[22] Remo DelGallo, the former Mayor of Pittsfield, and the owner of a bar on Newell Street near the General Electric plant, became aware of the extent of this contamination in 1980 after witnessing workers drilling approximately 200 test pits in the Newell Street area.[22] DelGallo reported to the *Berkshire Eagle* that he was aware of General Electric employees often dumping transformer oil into storm drains or locations near the plant; many of the storm drains emptied directly into the Housatonic River or Silver Lake.[22] At Bardo's Bakery, located near DelGallo's bar on the southern side of East Street, a basement sump pump was found to be saturated with PCB oil.[21] DelGallo's claims were initially discounted by company executives and state regulators; however, the Massachusetts Department of Environmental Quality Engineering (DEQE) discovered a large, infilled dumping site in the area, which contained material dating back to the 1940s.[22, 23] This discovery contradicted earlier reports from the DEQE that PCB contamination remained localized to the immediate vicinity of the plant.[19]

In addition to PCB transformer oil leaching into soils, groundwater, and surface waters near the plant, the filling of 11 former oxbows of the Housatonic River by the Army Corps of Engineers and General Electric in the 1940s dispersed PCB-contaminated material to various locations throughout the city.[24] The US EPA described that contaminated soils were used to isolate and fill the oxbows to straighten the river's course through Pittsfield.[24] Former Oxbows A, C, J, and K are presently located in or adjacent to Pittsfield's Lakewood neighborhood.[24]

Contamination in the Lakewood Neighborhood and Epidemiological Studies

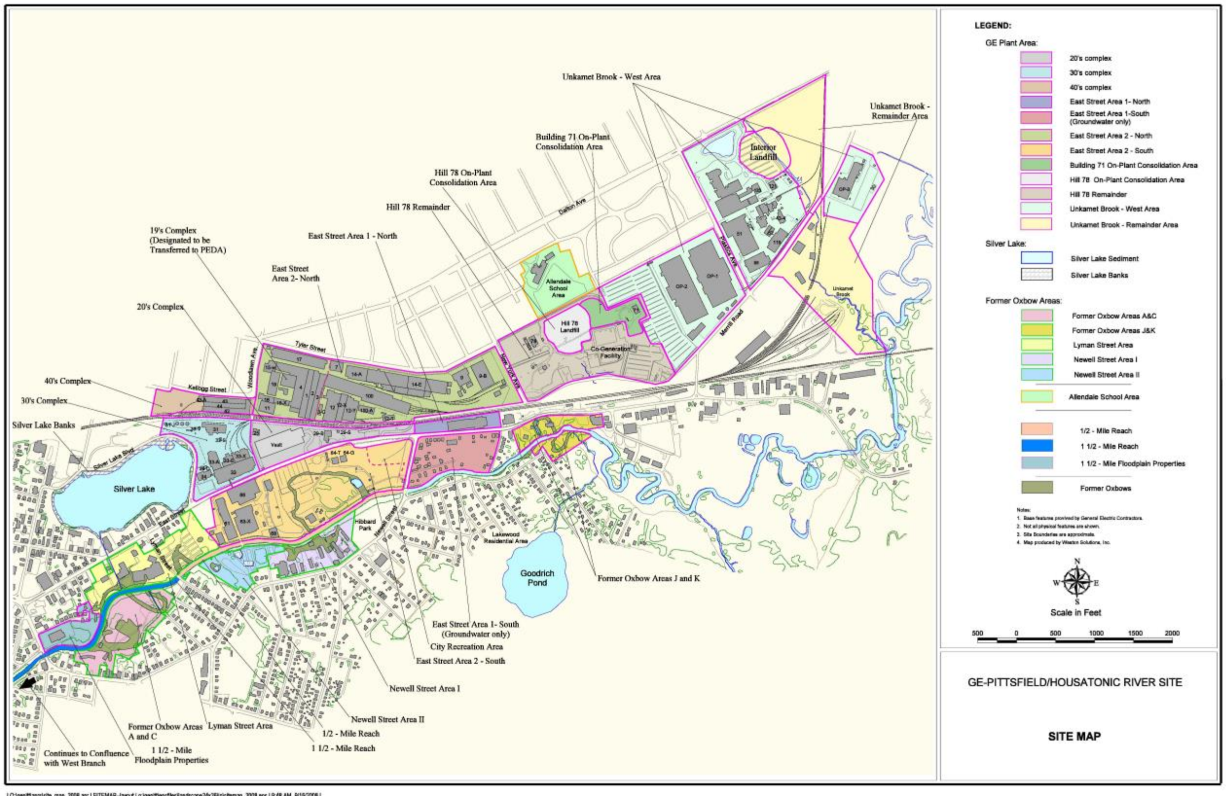
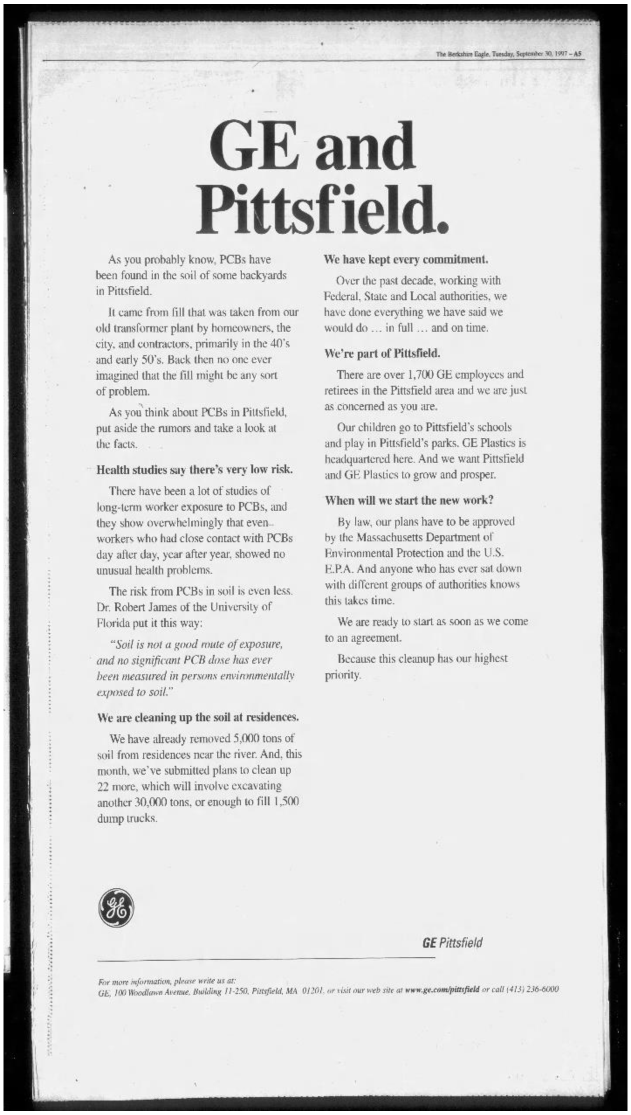


Figure 2: Map showing contaminated sites in Pittsfield. Source: United States Environmental Protection Agency.

The Lakewood neighborhood is a primarily residential area of Pittsfield that was developed in the early and mid-twentieth century.[25] Lakewood has suffered from high levels of PCB contamination because it is situated near the former General Electric plant and along the banks of the Housatonic.[17, 25, 26] The sites referenced by Mayor DelGallo and others are primarily located in the Lakewood neighborhood. An area of additional concern near Lakewood is Allendale Elementary School; the land on which the school and its playground is sited was once determined to contain a large volume of PCB-contaminated soil. In 1999, a cleanup at the Allendale School playground was completed and the site was determined to be safe.[27]

The Allendale School is adjacent to Hill 78 and Building 71, EPA designated PCB consolidation areas (known as the On-Plant Consolidation Areas, or OPCAs).[28] For decades, Hill 78 served as a disposal site for PCB-contaminated factory waste.[28] It encompasses 85 acres and protrudes roughly fifteen feet above the surrounding land.[28] Concentrations of PCBs in the unpaved surface soils of Hill 78 measured between 23 and 27 ppm, as high as 105 ppm in the surface soil of the landfill area itself, and as much as 840 ppm in unpaved areas outside of the landfill.[29] Subsurface soil PCB concentrations in the landfill were estimated to be as high as 18,741 ppm to 47,385 ppm.[29] In 1991, the site was covered with a synthetic geotextile cap and a layer of crushed stone as a temporary measure to contain contaminants.[28] Between 1999 and the early 2000s, several MassDEP and General Electric site visits occurred to assess conditions at Hill 78; these concluded that the landfill cap was in good condition and the site was secured from trespassing.[30, 31] Furthermore, the Centers for Disease Control and Prevention (CDC) determined that the site presented a greater public health hazard prior to its capping and that the site (as of the publication of the report in 2002) does not likely present a public health risk, contingent on the maintenance of institutional controls and proper monitoring of remedial activities by General Electric.[29] The CDC report also found no statistically significant evidence of cancer clusters or background levels of PCB compounds in blood serum among residents to be higher than amounts recognized as safe.[29]

Conterminous with and following the release of the 2002 CDC report, there has however been scrutiny surrounding the contamination of nearby residences with PCBs and the possible existence of PCB-associated cancer clusters, with a new cancer study to be completed by DPH in 2024.[33, 34] For years, General Electric had falsely claimed[34, 35] that PCBs cannot enter the bloodstream by interacting with contaminated soils and sediment.[19, 21] In 1997, an investigation by the *Boston Globe* resulted in the leak of a General Electric memo from 1948, which expressed that officials relied on Lakewood residents' willingness to take the contaminated fill as a convenient and inexpensive means of handling industrial waste.[34] In the memo, a GE manager admitted that "[Lakewood] is the last section anywhere near the plant where we can dump most anything that comes out of the factory."[34] After the publication of the 1997 *Boston Globe* article, and a companion piece in the *Wall Street Journal*, General Electric continued to deny that PCBs are associated with adverse health impacts by launching an advertising campaign in the



The Berkshire Eagle, Tuesday, September 30, 1997 – A5

GE and Pittsfield.

As you probably know, PCBs have been found in the soil of some backyards in Pittsfield.

It came from fill that was taken from our old transformer plant by homeowners, the city, and contractors, primarily in the 40's and early 50's. Back then no one ever imagined that the fill might be any sort of problem.

As you think about PCBs in Pittsfield, put aside the rumors and take a look at the facts.

Health studies say there's very low risk.

There have been a lot of studies of long-term worker exposure to PCBs, and they show overwhelmingly that even workers who had close contact with PCBs day after day, year after year, showed no unusual health problems.

The risk from PCBs in soil is even less. Dr. Robert James of the University of Florida put it this way:

"Soil is not a good route of exposure, and no significant PCB dose has ever been measured in persons environmentally exposed to soil."

We are cleaning up the soil at residences.

We have already removed 5,000 tons of soil from residences near the river. And, this month, we've submitted plans to clean up 22 more, which will involve excavating another 30,000 tons, or enough to fill 1,500 dump trucks.

We have kept every commitment.

Over the past decade, working with Federal, State and Local authorities, we have done everything we have said we would do … in full … and on time.

We're part of Pittsfield.

There are over 1,700 GE employees and retirees in the Pittsfield area and we are just as concerned as you are.

Our children go to Pittsfield's schools and play in Pittsfield's parks. GE Plastics is headquartered here. And we want Pittsfield and GE Plastics to grow and prosper.

When will we start the new work?

By law, our plans have to be approved by the Massachusetts Department of Environmental Protection and the U.S. E.P.A. And anyone who has ever sat down with different groups of authorities knows this takes time.

We are ready to start as soon as we come to an agreement.

Because this cleanup has our highest priority.

***GE** Pittsfield*

For more information, please write us at:
*GE, 100 Woodlawn Avenue, Building 11-250, Pittsfield, MA 01201, or visit our web site at **www.ge.com/pittsfield** or call (413) 236-6000*

Figure 3: 1997 General Electric advertisement refuting claims that PCBs are associated with adverse health impacts. Source: Berkshire Eagle, 1997.

local *Berkshire Eagle* and *North Adams Transcript* newspapers.[35, 36] Notably, the advertisement claimed that “there have been a lot of studies of long-term worker exposure to PCBs, and they show overwhelmingly that even workers who had close contact with PCBs day after day, showed no unusual health problems.”[36]

A growing body of research contradicts this claim; the EPA notes that in Pittsfield PCB exposure most commonly occurs after consuming fish from the Housatonic, children accidentally ingesting PCBs by touching or eating soils and sediment, or touching contaminated soils and sediment long enough for PCBs to be absorbed into the skin.[19, 21, 30] A 1998 EPA evaluation found that young children playing in and near contaminated portions of the river face noncancer risks (liver, nervous system, and developmental disorders) 200 times greater than the EPA’s safe threshold.[30] Teenagers growing up in areas adjacent to contaminated riverbeds (such as Lakewood), also face a 1 in 1000 risk of developing associated cancers, such as bladder cancer.[26, 30] Furthermore, 91 of the 93 river sediment test sites examined by the EPA showed evidence of PCB contamination.[30]

In 2022, a study was published examining the concentrations of PCBs in blood serum in 21 Lakewood residents, and in the air in the basements, living rooms, and outdoor air surrounding their ten homes.[17] While the authors acknowledge that significant remediation has been completed in Pittsfield and surrounding areas, including the removal of PCB-contaminated Fuller’s earth from some residential properties, contamination remains widespread.[17] The authors also refer to a shortcoming in existing environmental and epidemiological studies of PCB contamination in Pittsfield: the fact that most studies have monitored only the presence of persistent PCB congeners in environmental and human samples.[17] Vapor phase PCBs, congeners present in indoor and outdoor air, are an under-investigated source of continuous exposure. These more volatile congeners are not as persistent in the human body, meaning they are less likely to present during serological examination.[17] Nevertheless, inhalation of vapor phase PCBs is an effective route of exposure and has been associated with altered neurobehavior, organ-specific damage, cancers, cardiovascular disease, thyroid disease, reproductive abnormalities, and cognitive dysfunction.[37, 38, 39]

The study found blood serum PCB levels among the individuals sampled to be approximately four times higher than among the background US population.[17] Within homes, PCB concentration was the highest in basement air – about twice as high as in living rooms and above-ground work areas.[17] Still, PCB concentration in the air in above-ground, indoor living and work areas was four times that of outside air.[17] The congeners found in the air were more volatile, lower-chlorinated congeners, and distinct from the higher-chlorinated coplanar Aroclor-1254 and Aroclor-1260 congeners used in transformer oil.[17] These lower-chlorinated congeners are found in low concentrations in the trademarked transformer oils, but most likely originated from anaerobic bacterial dechlorination of the highly chlorinated PCB congeners.[40] Conversely, the heavier Aroclors were found at very low concentrations in the air but are the dominant PCB compounds in human blood and soil in Pittsfield. The results of this study suggest that the Lakewood neighborhood continues to experience dispersed PCB contamination in soil and household air.[17]

RESEARCH QUESTION

Past remediation efforts of PCB contamination in Pittsfield and the Housatonic River have been criticized by local environmental advocacy groups, environmental attorneys, and residents.[21, 34, 41] Many of the remediation strategies have called for *in-situ* containment of PCB contaminated materials in landfills, or removal of the material to an offsite containment area.[24, 41, 42] This work aims to present a range of novel technologies that remediate contamination from soil and groundwater *in-situ*, rather than simply containing or removing the soil to other locations. Contaminated locations in Pittsfield suitable for remediation pilot programs are highlighted here, along with site-specific recommendations and plans.

This thesis seeks to:

- Assess and inventory sites contaminated and previously contaminated with PCBs in Pittsfield, Massachusetts.
- Identify and fill deficits in current remediation efforts, in accordance with community needs and values, to support the health, safety, and welfare of Pittsfield residents.
- Investigate low-impact solutions to remediate PCB contaminated soils and groundwater on-site rather than relocating and containing the soil in landfills.
- Locate and assess various contaminated sites to provide recommendations for targeted, site-specific remediation efforts.

METHODOLOGY

This work takes a mixed-method approach to holistically assess and inventory the current conditions of various contaminated and previously contaminated sites in Pittsfield. Much of this work consists of a comprehensive review of existing site assessments, as well as a review of established and novel scientific literature detailing approaches to manage and remediate sites contaminated with PCBs.

Literature Review

This work synthesizes literature from a variety of disparate disciplines and sources including reports and site evaluations conducted by the United States Environmental Protection Agency (US EPA), the Massachusetts Department of Environmental Protection (MassDEP), the Massachusetts Department of Public Health (DPH), the City of Pittsfield, and the third-party firms involved with the assessment and remediation of contaminated sites. These reports were obtained via online database searches and direct correspondence with the agencies themselves. Since many early reports of the contamination originated from independent “citizen scientists” and activist groups, reports from local environmental groups such as the Housatonic River Initiative and the archives of the Berkshire Eagle newspaper were extensively searched.

To understand the chemical properties of PCBs and identify best management practices for remediation, database searches of chemical engineering, environmental science, and environmental engineering journals were consulted. Frequently referenced journals include *Environmental Science & Technology*, *Chemosphere*, *Environmental Engineering Science*, *Environmental Toxicology Chemistry*, and the *Journal of the*

Association of Official Analytical Chemists. Other references include books and manuals, especially *Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater*,[43] *Cost and Performance Report for Persulfate Treatability Studies*,[44] and *Pocket Guide to Screening Small Water Diversions*,[45] which detail the implementation and design of several site remediation technologies. Most of these manuals were sourced through the online library of the Contaminated Site Clean-Up Information System (CLU-IN), a repository of site remediation technical literature developed by the US EPA.[46]

Site Assessments and Planning

Observational assessments of contaminated sites were conducted at Brattle Brook Park, the Lakewood neighborhood, and areas located on the periphery of the former General Electric Plant.[f] The Nearmap satellite imaging software[47] was used to obtain high-resolution aerial images of locations throughout Pittsfield that could not be accessed due to restrictions on entry. A combination of Nearmap imagery and ArcGIS Pro mapping tools were used to measure sites, namely the Hill 78 and Building 71 On-Plant Consolidation Areas to determine the appropriate siting and design characteristics of bioretention areas. ArcGIS Pro and the United States Department of Agriculture (USDA) Web Soil Survey tool were used to create maps of sites and assess hydrological and agronomic conditions of the areas of study.[48] Independent soil sampling in Brattle Brook Park, the Goodrich Pond

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[f] These observations occurred in September and October 2023, and consisted of walk-throughs, photography, and note-taking to provide visual reference and context for locations referenced in this thesis. These were conducted to aid in the site planning and assessment process. Access to former General Electric sites is prohibited, and observations of these sites occurred from behind the electric fence surrounding them.

area, and the General Electric site was not feasible within the scope of this thesis, primarily due to entry restrictions, the limitations of specificity of commercially available test kits, and an inability to obtain specialized excavation equipment, permitting, and the administration of an EPA certified mass spectrometry test. Assessments of soil quality and PCB soil concentrations were obtained via the USDA Web Soil Survey database and the government agencies involved with the testing and remediation of contaminated sites.

KEY LOCATIONS AND EXISTING CONDITIONS

Since the late 1990s, some significant efforts have been made by state and federal regulatory agencies to remediate, remove, or contain PCB-contaminated soils in Pittsfield.[49] This has included initiatives to remediate portions of the Housatonic River within Pittsfield, the remediation of Silver Lake (a body of water adjacent to the former plant that was used as a dumping site), the remediation of the Allendale School and some contaminated properties in the Lakewood neighborhood, and the construction of the two on-plant consolidation areas to store dredged materials from waterbodies and contaminated soils.[49, 50, 51]

Despite these ongoing efforts, city residents remained concerned about the presence of PCB contamination in Pittsfield and remediation work is far from complete. In particular, the two on-plant consolidation areas raise the concern that a large amount of highly contaminated material (over 200,000 cubic yards) is stored in the densely populated city limits.[28] Although these facilities are highly secured and monitored, risks can arise from storing toxic PCB waste in populated areas, which will be explored further in this section. Additionally, there are contaminated sites in the city such as Goodrich Pond where there are no documented remediation efforts.[19, 52, 53] This section of the thesis will analyze the existing conditions of five key contaminated and remediated sites in Pittsfield:

1. The site of the former General Electric plant
2. Hill 78 and Building 71 On-Plant Consolidation Areas
3. Silver Lake

4. Goodrich Pond
5. Brattle Brook Park

Three of the sites listed above – Brattle Brook Park, Silver Lake, and the former plant site – will not be discussed in the "Specific Recommendations" portion of this thesis. For Brattle Brook Park, this is because findings suggest that there is no current risk of exposure to PCB contaminants within the park.[54] Regarding Silver Lake and the remediated portions of the Housatonic River, comprehensive efforts have been completed to clean up the contaminated filled oxbows and remove contaminated sediments from the river and lake.[24, 49] The site of the former General Electric Plant, excluding the Hill 78 and Building 71 consolidation areas, has also undergone remediation, and is slated to be redeveloped into a business park.[50, 55]

Former General Electric Plant Site

The site of the former General Electric plant consists of 324 acres of land which includes ten specific Removal Action Areas (RAAs).[50] Most of these areas are currently access-restricted brownfield land that formerly contained the buildings and other improved lands of the General Electric facility. Portions of the site are bisected by a CSX rail right-of-way, and some small CSX-owned facilities are located on the former plant site.[50] The present conditions and remediation statuses of the ten RAAs are described below.

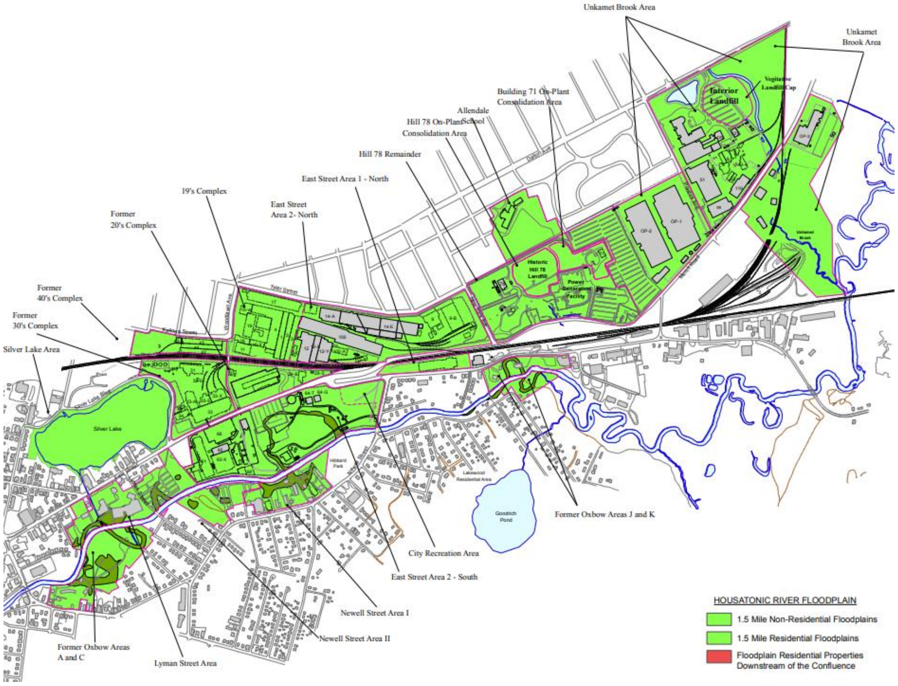

Figure 4: Map depicting the location of the RAAs. Source: United States Environmental Protection Agency.

Locations of Former Manufacturing

Six of the ten RAAs (40s Complex, 30s Complex, 20s Complex, East Street Area 2 – South, East Street Area 2 – North, and East Street Area 1 – North) were locations of former manufacturing buildings, substations, and the rail line (which has current freight service) that serviced the plant.[50] The built environment of these six sites prior to the demolition of the plant were largely similar, consisting of a mix of manufacturing and commercial structures, asphalt paving, and some areas of open land.[50] As of 2013, all six of these sites have received certificates of completion[g] from the US EPA and are undergoing post-removal inspection, monitoring, and maintenance activities.[50] These RAAs are slated to

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[g] Certificates of Completion, formally known as a Superfund Remedial Action Project Completion (RAPC), refers to the implementation of the discrete scope of activities (Remedial Action Objectives, or RAOs) specified in the cleanup action plan. This performance standard was established in 2011 to coordinate and communicate progress towards the completion of cleanup activities.[71]

be redeveloped into the William Stanley Business Park, a 50,000 square foot multi-tenant commercial complex.[55] As of 2023, the developer has secured nearly $10 million in funding to bring the site to a developable state, including federal American Rescue Plan Act of 2021 (ARPA) funding and state economic development and brownfields grants.[55]

Unkamet Brook RAA

The Unkamet Brook RAA encompasses 135 acres and consists of Unkamet Brook and its associated floodplain, wetlands, and a landfill once owned and operated by General Electric. Unkamet Brook is a small stream with its source north of the former plant location.[50] The brook bisected the former landfill and flowed into a marsh situated on the former plant site; it then flowed further south through the marsh and converged with the Housatonic River.[50] Notably, the marsh was heavily contaminated with PCBs, and the brook converged with the Housatonic River north of the section that had been remediated.[56] Therefore, contaminated material had likely been entering the river via Unkamet Brook, which had not yet been remediated.[56] Furthermore, the flow of Unkamet Brook had gone unmonitored until 2006, meaning that there was no quantification of pollutant transport from the brook into the river.[56, 57]

Remediation in the Unkamet Brook RAA began in December 2014, and was mostly completed by October 2016.[57] Significant actions included the rerouting of the 600-foot section of Unkamet Brook that bisected the landfill, the realignment of sewer lines, water treatment, dredging and removal of contaminated soils, and the capping of the former landfill.[50] Additionally, invasive plant species were removed from the brook and the wetland.[50] In March 2018, the US EPA granted a Certificate of Completion of the remediation activities, and General Electric is performing the required post-removal control activities (inspection, monitoring, and maintenance).[50]

Analysis of Existing Conditions

The redevelopment of the six former plant RAAs may require further remediation activities, including the completion of Environmental Site Assessments and additional work to render the area suitable for development.[58, 59, 60] Therefore, these sites may experience further remediation as a component of the redevelopment initiative. However, the proximity of the Hill 78 and Building 71 sites to the business park may be concerning (see "Deficits in Remediation Practices" for further information). The Unkamet Brook area has been satisfactorily remediated;[50] however, the discharge of potentially contaminated material from the brook into the Housatonic during and after remediation warrants continued monitoring of the Housatonic to track potential contamination.[56, 57]

Hill 78 and Building 71 On-Plant Consolidation Areas

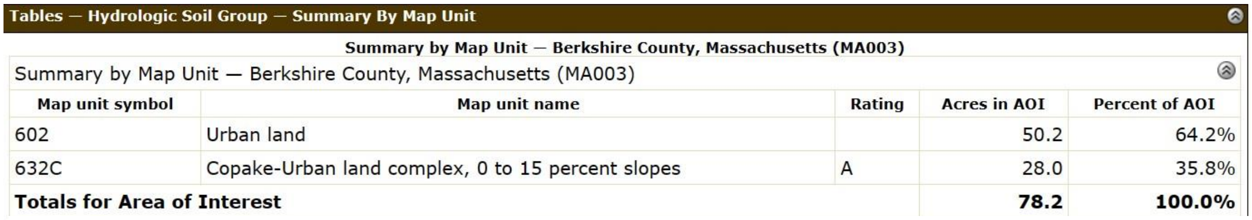
There are two *in-situ* On-Plant Consolidation Areas (OPCAs) for PCB-contaminated material in Pittsfield; the Hill 78 and Building 71 sites. Although these OPCAs are two of the RAAs located within the General Electric plant site,[50] they exhibit characteristics distinct from the RAAs and warrant further remediation actions. Hill 78 encompasses roughly six acres of land that was historically used by General Electric to dispose of excavated materials and a variety of other debris generated during construction or within the plant.[28] In 1991, General Electric installed a temporary cap on the landfill. After designation as a consolidation area by the EPA, approximately 134,500 cubic yards of contaminated material was disposed of at the site between 1999 and 2009.[61] Material deposited at Hill 78 was required to contain no greater than 50 ppm of PCB.[61] After the area was filled in 2009, it was sealed with a multilayer cap consisting of an impermeable high-density polyethylene (HDPE) liner, a geosynthetic drainage composite layer, eighteen inches of sand, and six inches of topsoil with a vegetative cover.[28, 62]

Figure 5: The Hill 78 OPCA. Source: self.

The Building 71 site encompasses 4.4 acres of land and is located immediately to the East of Hill 78. It is situated on the former site of Building 71 of the General Electric plant which was demolished to accommodate the landfill.[28] Demolition included the removal of storm drains associated with the former building, and the construction of two stormwater basins to manage the flow of clean runoff from both sites.[62] Between 2001 and 2006, approximately 110,500 cubic yards of material containing more than 50 ppm of PCB (designated hazardous waste) was deposited at the site and it was subsequently sealed using the same cap design as the Hill 78 site.[28] In addition, the Building 71 site includes a bottom liner and leachate collection system.[62] In 2011, Certificates of Completion were issued for both sites and General Electric is responsible for performing Post-Removal Site Control Activities which include inspection, monitoring, and maintenance.[28, 62]

Agronomic and Topographic Conditions of the OPCAs

The soil composition of the OPCAs has been classified as Copake-urban land complex by the USDA Soil Survey.[48] The Copake-series soils native to the site consist of loamy, stratified drift and glacial outwash. In the surface layers and subsoils, permeability ranges from moderate to moderately rapid; in the substratum, permeability can range from moderately rapid to rapid.[63]



Tables — Hydrologic Soil Group — Summary By Map Unit

Summary by Map Unit — Berkshire County, Massachusetts (MA003)

Summary by Map Unit — Berkshire County, Massachusetts (MA003)

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
602	Urban land		50.2	64.2%
632C	Copake-Urban land complex, 0 to 15 percent slopes	A	28.0	35.8%
Totals for Area of Interest			**78.2**	**100.0%**

Figure 6: Table showing soil composition at the OPCA sites. (Source: USDA Web Soil Survey)

Due to the site's use as a landfill and its history of development, the native Copake-series soils have been mixed with urban land soils (thus the classification of "Copake-Urban land complex").[28, 48] Urban land soils refer to soil that has been disturbed by the addition of impervious surfaces, or previous improvements to the soil.[64] In many cases, urban soils consist of areas where the underlying soil has been cut away, filled, or otherwise disturbed.[64] The Hill 78 OPCA rises approximately 15 feet above the surrounding topography, and much of this 15-foot mound consists of landfill deposited at the site by both General Electric and during the remediation process.[28] Therefore, it can be assumed that the surface layers and subsoils consist primarily of urban land and mixed filled soils, while the substratum contains a larger proportion of native Copake soils.[63, 64]

Considering the OPCAs consist of contaminated fill and other materials from various sources (likely including manmade industrial and building debris), the OPCA urban fill likely contains varied soil types.[65] The underlying Copake-class soils are assigned a type A rating, indicating high permeability and a high rate of groundwater recharge.[48] The USDA did not assign a soil type to urban land soils, likely because of their varied typologies.[64] However, urban soils are typically disturbed and exhibit compaction from prior construction and demolition activities.[64] Therefore, permeability is impaired, and these soil types frequently induce runoff.[65] As a function of the landfill's design, permeability is further impaired or eliminated by the addition of the cap designed to retain contaminated materials *in-situ*.[28] Understanding the permeability and composition of soils on-site is critical to determining the applicability and requirements for remediation methods, especially *in-situ* chemical oxidation.[43] Additionally, soil composition and permeability is an important step in determining the risk of pollutant mobilization and groundwater recharge.[66]

Analysis of Existing Conditions

Although the landfills have been capped and secured according to established protocol, and a 2021 monitoring report from the US EPA shows that contamination remains largely contained to the containment area[67] there are inherent risks to storing large quantities of contaminated material in a densely populated urban area.[68, 69, 70] Furthermore, monitoring of the landfill is contingent on the party responsible for completing post-remediation activities, including inspection and maintenance.[71] In this case, the responsible party is General Electric.[28] The risks of landfills and third-party monitoring are explored further in "Deficits in Remediation Practices." The presence of a large mass of contaminants in a small and confined location may render the site suitable for *in-situ* remediation methods.[43] Rather than indefinitely containing PCBs on-site, these methods would remediate and reduce the concentration of PCBs without the need for earth removal or transportation to a different site, or indefinite containment.[43] Site-specific recommendations for the use of these *in-situ* methods are explored in the discussion and recommendations portion of this work.

Silver Lake

Silver Lake is located directly to the west of the former plant site and has an extensive history of contamination from both PCBs and a wide range of other industrial pollutants.[72, 73] The lake presently receives stormwater flow from several city outfalls, in addition to an outfall permitted under the National Pollutant Discharge Elimination

System (NPDES).[h] [51] The NPDES-permitted outfall receives stormwater from a remediated section of the former plant area, and the lake then drains into the Housatonic River.[51] Documented pollution of Silver Lake dates to the early twentieth century, several decades before the production of PCBs began in Pittsfield.[74] The lake was the site of two documented oil spills and was used as a dumping site for sewage and trash. In 1923, the surface of the lake caught fire due to the buildup of flammable contaminants.[74] PCBs were introduced into the lake shortly after production commenced at the Pittsfield plant circa 1932.[51] Its proximity to the plant and the quantity of stormwater outfalls entering the lake meant that PCB waste disposed of in the vicinity of the plant could readily enter the lake.[51, 73] Prior to remediation, moderate to high amounts of PCBs had been detected in the surface water, sediments, and bank soils.[72, 73] After entering the lake, PCBs subsequently flowed into the Housatonic River.[51]

Figure 4: Silver Lake in relation to the former General Electric Plant 30s Complex. Source: United States Environmental Protection Agency

Although Silver Lake was contaminated for nearly a century, an aggressive remediation approach led to the lake being classified safe for certain recreational uses in 2014, excluding the consumption of fish caught from the lake.[51] Despite this

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[h] An EPA-administered program created in 1972 under the Clean Water Act to prohibit the discharge of pollutants from a point source (i.e. a factory, water treatment plant, or other clearly defined facility or land use) without an NPDES permit. The NPDES permit regulates what and how much the site can discharge and stipulates specific monitoring and reporting requirements to ensure that the discharge does not negatively impact water quality or public health. These requirements are tailored to each permit, in order apply the requirements of the Clean Water Act to specific sites.[195]

determination, James McGrath, the parks, open spaces, and natural resources manager for the City of Pittsfield, commented in 2014 that although the restriction on swimming had been lifted, the City does not encourage swimming in the lake.[74] As of 2020, the lake is still included in the Massachusetts Integrated List of Waters as a Category 5 impaired waterbody due to the presence of PCBs in fish tissue.[52] Remediation consisted of the dredging of 400 cubic yards of PCB “hot spot” sediments adjacent to a historic General Electric outfall, removal of near-shore sediments, bank soil cleanup, and the placement of a fourteen-inch-thick organic carbon and slurry cap along the entire bottom of the lake.[51] The banks were restored using clean fill and native vegetation planting, and a walking trail was constructed around the perimeter of the lake. General Electric is tasked with post-remediation monitoring activities as the responsible party.[51] The successful restoration of Silver Lake provides a potential framework for the remediation of Goodrich Pond, a contaminated waterbody in Pittsfield that is yet to be remediated and discussed further below.

Goodrich Pond

Goodrich Pond is situated in the urban Lakewood neighborhood of Pittsfield, Massachusetts adjacent to the Housatonic River and is bordered to the East and South by the Brattle Brook Park, a protected nature reserve.[53] A small, unnamed stream flows into Goodrich Pond from the Housatonic River through the Lakewood neighborhood.[53] The pond itself encompasses an area of 15.4 acres, and the area of the pond's watershed includes 63 acres of land. The total area of the pond and the watershed encompasses 78.4 acres. Of the soil types found within the Goodrich Pond Watershed, 27 acres consist of Type A soil, 3.9 acres of Type B soil, 0 acres of Type C soil, and 32.2 acres of Type D soil. Therefore, the watershed primarily consists of Type A "recharge soils," such as Pittsfield-urban land complex, and conversely Type D soils with high runoff potential.[48, 63, 64]

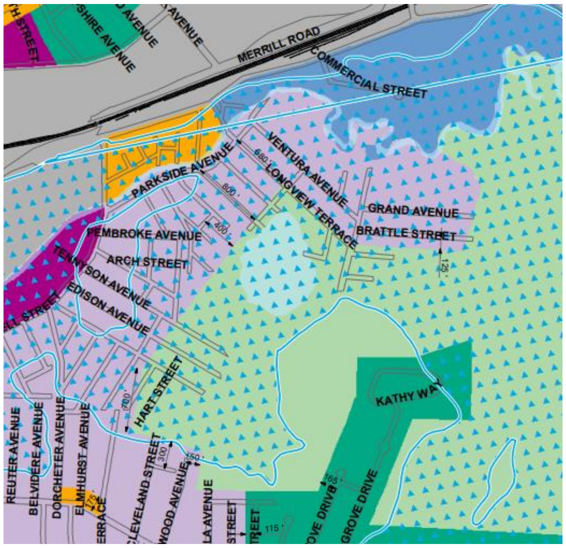

Figure 8: Portion of the City of Pittsfield zoning map highlighting the vicinity of Goodrich Pond. Light green indicates recreational open space; light purple indicates R-6 zoning, orange indicates general business. Source: City of Pittsfield.

Precipitation, evaporation, pond evapotranspiration, and discharge amounts were calculated using the Massachusetts average precipitation rate of 48 inches per year and evapotranspiration rate of 24 inches per year.[48] Recharge and runoff calculations were obtained using soil classification data from the United States Department of Agriculture (USDA) Web Soil Survey.[48] Total discharge amounts to 156.8 AFY. 75.6 AFY of water is retained through recharge, and 50.6 AFY flows out as runoff.[48] Full calculations are documented in Appendix A.

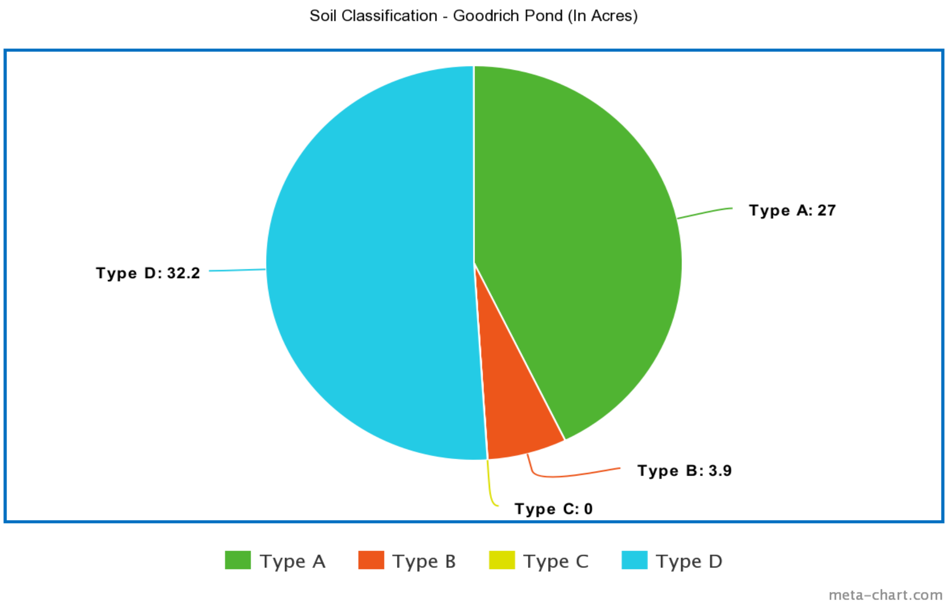

Figure 9: Chart depicting share of soil type classification within the Goodrich Pond Watershed, in acres. Source: USDA Web Soil Survey.

PCBs are likely to enter Goodrich Pond through groundwater (subsurface) and may further the pond via the stream that connects to the Housatonic River. The low vapor pressures of PCBs, coupled with their propensity to bind to fine soils, organic particles, and sediments in aquatic environments, means that transport from local sites of contamination to other sites occurs readily.[75] The aforementioned vapor phase PCBs, the lightweight congeners that can spread through the air and are found in the surrounding Lakewood neighborhood, may pose additional contamination risks to the pond.[17, 37] Understanding potential pollutant transport paths into the pond is essential to creating a comprehensive remediation strategy for the pond and nearby contaminated sites. Because of the existence and identification of these pathways, the remediation of Goodrich Pond is contingent on the successful remediation of nearby sources of contamination, including Hill 78 and Building 71 in addition to the remediation of contamination in the pond itself.[17, 76] Measures to address the transport of pollutants into the pond, including contaminated fish[76] are addressed later in this thesis.

Goodrich Pond Water and Soil Assessments

In the late 1990s and early 2000s, a multi-agency investigation into PCB contamination at Goodrich Pond and the abutting Brattle Brook Park was conducted.[76, 77] This investigation produced several reports assessing various routes of contamination in the waterbody: the presence of PCBs in fish tissue and soils and sediments in the pond, its banks, and the surrounding area.[76, 77]

Fish Tissue Sampling

A 2001 report titled “Health Consultation, General Electric: Goodrich Pond” prepared by the Environmental Toxicology Program of the Massachusetts Department of Public Health (DPH) investigated the presence of PCBs in the tissue of fish captured in the pond.[76] Since the release of the report, Goodrich Pond has retained a classification of “Category 5 – Waters Requiring a TMDL” and is included in the Massachusetts 303(d) list of impaired waterbodies.[52] PCBs are the primary pollutant of concern in Goodrich Pond; the current waterbody assessment includes a TMDL solely for PCB contamination and no other pollutants are referenced in literature regarding the pond.[78]

The 2001 report analyzed five residences located adjacent to the pond, in addition to the pond itself, and found that two had required remediation. Species of fish sampled in

Goodrich Pond consisted of bluntnose minnow, brown bullhead, bluegill, common shiner, fallfish, golden shiner, goldfish, largemouth bass, pumpkinseed, smallmouth bass, yellow bullhead, and yellow perch.[76] Several of these species are popularly consumed by recreational fishers, and the pond's proximity to residences raises concern that individuals were consuming potentially contaminated fish.[76]

The FDA action level for PCB concentration in fish tissue is 2 ppm; however, the DPH applies a safety factor of 2 to the FDA action level to account for populations more sensitive to PCB exposure, meaning this study adopted an action level of 1 ppm.[76] The analysis found that the average PCB concentration in the collected filleted fish samples was 0.9180 ppm. The average concentration of PCB in bluegill and largemouth bass fillets exceeded 1.0 ppm, with average concentrations of 1.2208 ppm and 2.3838 ppm, respectively. Five of the nineteen bluegill samples contained PCB concentrations above 1 ppm, with a range of 1.6166 ppm and 11.2803 ppm.[76] Since largemouth bass has a legal-size limit (meaning that all largemouth bass less than twelve inches in length must be released back into the pond), only samples from potentially consumable fish above the legal-size limit were considered.[76] Largemouth bass above the size limit exhibited an average tissue PCB concentration of 2.3838 ppm.[76]

The report notes that the wide variations in tissue concentration and the presence of an intermittent stream connecting the pond to the Housatonic likely allows for contaminated fish to enter the pond from the river, although information is not available to definitively quantify this.[76] As a precautionary measure, DPH classified Goodrich Pond as a Category 2 Public Health Hazard under the criteria of the Agency for Toxic Substances and Disease Registry (ATSDR).[76] DPH subsequently issued a fish consumption advisory for Goodrich Pond, and state and local officials enclosed the pond with a chain-link fence to discourage entry.[76] Makeshift signage depicting images of deformed fish was posted by members of the Housatonic River Initiative to caution residents against consuming fish from the pond, after DPH allegedly failed to post signage.[79]. This report shows that contaminated fish may continue to enter the pond, provided that the stream entering the pond from the Housatonic remains unscreened. While remedial activities conducted in the river may have reduced the risk of contamination to river fish,[24, 50, 51, 57] it is possible that older fish alive prior to remedial efforts pose a risk of entering the pond, due to bioaccumulated PCB contamination.[80, 81] For instance, largemouth bass have an average lifespan of 16 years,[82] and a maximum observed lifespan of 23 years.[83] Therefore, at the time of writing, it is possible that there are fish in the Housatonic that were alive prior to the 2011 issuance of the Certificate of Completion for the Housatonic River cleanup.[84] Methods to screen the stream entering Goodrich Pond are discussed further in this thesis.

Soil and Sediment Sampling

In 1999, a joint investigation conducted by the Massachusetts Department of Environmental Protection (MassDEP) and the United States Environmental Protection Agency (US EPA) assessed the presence of PCBs in the subsurface sediments and banks of the pond at varying depths.[77] In surficial sediments, PCB concentrations above 2 ppm were observed in only 1 of 38 samples. In deeper sediments (between 6 inches and 12 inches below the surface), concentrations ranged from non-detect to 4.4 ppm, and concentrations above 2 ppm were detected in 10 of 99 samples.[77] No PCBs were found in any samples of soil collected at a subsurface depth of 4 feet or greater.[77] At the time of the report's publication, bank soil investigations had occurred at four locations on parcel K9-1-33 (see Appendix B).[77] Results indicated surface soil PCB concentrations of up to 2.5 ppm in surface soils and near-surface soil concentrations below 2 ppm.[77] The findings of the 1999 report indicated that no further action was required regarding contamination in soils and sediments in Goodrich Pond, despite the presence of PCB concentrations greater than 2 ppm in some samples.[77] However, the report did call for further analysis of soils surrounding parcel K9-1-33.[77] These findings indicate that PCB contamination likely remains in dispersed locations in pond sediments at medium depth (6 to 12 inches below the top layer of sediment), and remedial activity may be warranted.

Analysis of Existing Conditions

The source of contaminated fish found in Goodrich Pond requires further investigation. While it is likely that some of these fish enter the waterbody via the Housatonic River, the wide variance in PCB concentrations found in the fish tissue may indicate that some of this contamination is sourced natively within the pond.[76] Sediment sampling in Goodrich Pond demonstrates that some scattered areas of soil exhibit concentrations of PCB above 2 ppm.[77] PCBs bioaccumulate in organisms; the relatively long biological half-life of PCBs results in the aquatic organisms absorbing the substance faster than they can excrete or catabolize it.[80, 81] Even if environmental levels of PCBs are not particularly high, their lengthy biological half-life increases the risk of chronic poisoning of aquatic organisms.[81] PCBs can enter the food chain through accumulation and uptake of by aquatic plants and biomagnify through progressively higher trophic levels.[80] Biomagnification refers to the increase in concentration of the pollutant as it moves to higher trophic levels (the food chain).[85] A 2019 study on Lake Chapala in Mexico, a lake with PCB concentrations comparable to several of the samples taken in Goodrich Pond, found evidence of PCB bioaccumulation among several species of fish.[80] Herbivorous fish exhibited a higher potential to bioaccumulate PCBs, in addition to those that inhabit the benthic zone of the lake.[80] Therefore, not all species of fish are equally impacted by the presence of PCBs in a waterbody.

Brattle Brook Park

Soil contamination conditions and former land uses in Brattle Brook Park are closely related to those of Goodrich Pond, considering that a significant portion of the Goodrich Pond watershed consists of Brattle Brook Park.[48] The history of the park begins in 1914 when Battista Alessio purchased a large tract of vacant land to operate a dairy farm.[86] The Alessio Brothers Dairy Farm thrived through the first half of the twentieth century and shaped the current conditions in Brattle Brook Park; thirty acres of wetlands on the site were filled and the park today consists primarily of large swaths of former pasture, wetlands, and several forested areas.[53, 86] After the farm closed in 1969, the land was sold to the City of Pittsfield for $148,000 as the family did not want the land to be subdivided and developed.[86] The City purchased the 142 acres of land for use as a park in

1972, using a Land and Water Conservation Fund grant provided by the United States Department of the Interior.[87]

Historic Contamination

According to Tim Gray of the Housatonic River Initiative, an environmental advocacy group seeking to remediate and decontaminate PCB pollution in the Housatonic River watershed, creosote bricks used to soak up PCB oil were widely disposed of at the Brattle Brook Park site.[79] Through the 1990s and 2000s, Gray reported that many of the bricks remained at the site and that local youth would sometimes handle or play with the contaminated bricks.[79] The possible continued presence of PCB-containing creosote bricks at the site warrants further investigation and may present risks for uninformed visitors to the park, especially children who are unaware of the purpose of the bricks.

Figure 10: A PCB-saturated creosote brick in Brattle Brook Park. Source: Heather Bellow, Berkshire Edge, 2016.

Evaluations of Contamination

In 2007, a study conducted by Stantec Consulting Services, Inc. in collaboration with the City of Pittsfield, evaluated PCB contamination at the site of a former General

Electric dumping site located in the present-day Brattle Brook Park.[54] Thirteen test pits were dug to assess soil conditions; this exercise determined that the former dump encompassed an area of approximately 20,000 square feet.[54] In addition to surface waste consisting primarily of metal and concrete, buried waste consisted largely of organic soil mixed with glass, metal, bricks, wood, and ash.[54] In most locations the depth of this debris did not exceed 4 feet below the surface.[54] When assessed for the presence of PCBs, none of the samples revealed concentrations above method detection limit; the *National Recommended Water Quality Criteria: 2002 EPA 822-R- 02-047* sets a detection limit for PCBs at 0.0005 ppm.[88] This is largely due to the age of the fill, coupled with the coarse nature of the fill and the native soil.[54, 64] Sampling did, however, indicate concentrations of cadmium, mercury, and selenium greater than action thresholds.[54]

Analysis of Existing Conditions and Specific Recommendations

Findings suggest that remediation to address heavy metal pollution in the former dump site is warranted; however, such remediation activities fall outside the scope of this thesis. Since the assessment by MassDEP and Stantec in 2007 showed no concerning levels of PCB in soil due to age of dump, and since the location of the park is fairly removed from human settlement, remediation of PCBs is not warranted.[54] Despite the findings of the report, area residents remained concerned about contamination because of the site's former use and the possible continued presence of PCB-containing creosote bricks on-site.[53] To help alleviate community environmental concerns, a thorough canvassing of the park could be completed to remove any remaining contaminated material, including creosote bricks and other industrial materials discarded by General Electric.

DEFICITS IN REMEDIATION PRACTICES: COMMUNITY ORGANIZING AND LEGAL CHALLENGES

Community Organizing and Litigation

Local advocates, including the Housatonic River Initiative, have argued that the remediation of the Housatonic River and other contaminated sites through excavation and removal of material, or the on-site containment of material, may pose continued risks to community and environmental health.[21, 89, 90] The Housatonic River Initiative advocates for a "treat, don't dump" approach to remediating the remaining portions of the Housatonic River; in 2000, the group opposed the consent decree between General Electric, the Commonwealth of Massachusetts, and the federal government that authorized the removal and storage of contaminated sediments in the Hill 78 and Building 71 OPCAs.[19, 21] The challenge, which proved unsuccessful, cited the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (also known as CERCLA or "Superfund").[21] CERCLA authorizes the federal government to respond to and remediate hazardous substances released into the environment and includes the following clause in Section 9621(b) of the act:

> "Remedial actions in which treatment which permanently and significantly reduces the volume, toxicity, or mobility of the hazardous substances, pollutants, and contaminants is a principal element, are to be preferred over remedial actions not involving such treatment. The offsite transport and disposal of hazardous substances or contaminated materials without such treatment should be the least favored alternative remedial action where practicable treatment technologies are available."[91]

In 2016, EPA issued Order-1, which required General Electric to remove the remaining PCBs from the river to an out-of-state site.[92] General Electric successfully appealed the requirement that the PCBs be moved to an out-of-state location to the US EPA Environmental Appeals Board.[93] In 2020, the final cleanup decision for the “Rest of River” downstream areas was released.[94] Like the 2000 plan to remediate the portions of the river adjacent to the plant, the “Rest of River” plan is again incongruous with Section 9621(b) of CERCLA.[91] In accordance with the appeal to keep the PCB waste in state, this plan calls for the disposal of PCB contaminated sediments at a landfill in the nearby town of Lee, Massachusetts, which was authorized by the town after a closed-door partial settlement agreement (PSA) between the Lee Select Board and General Electric in February 2020.[93] The signatories of the PSA included the Town of Lee, the City of Pittsfield, several other Housatonic towns in southern Berkshire County, the US EPA, and General Electric.[93] Part of the agreement included General Electric paying a $25 million donation to the Town, and the landfill is designed to be highly protective of human health.[89] However, if Lee rejects the site, this donation will not be offered.[95] Residents, abutters, and local environmental groups have expressed concerns about the landfill.[89]

In 2021, attorneys representing the Housatonic River Initiative and the Housatonic Environmental Action League appealed the proposal before the US EPA’s Environmental Appeals Board.[96] The appeal argued that the decision to request on-site containment of the waste was arbitrary and capricious, along with the failure of the US EPA to investigate the use of bioremediation and thermal desorption[i] technologies in the Rest of River cleanup, which is contrary to CERCLA section 9621(b).[97] In February 2022, the Environmental Appeals Board denied the appeal, holding that the petitioner failed to meet

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[i] The use of a machine, called a thermal desorber, to heat soils and sediments. This breaks down and transforms organic contaminants into vapors to separate them from the solid media.[196]

their burden of demonstrating that the US EPA cleanup methodology was erroneous, and that the investigation of alternate remediation technologies was not within the scope of the Board's review.[98]

In 2023, the Town of Lee filed a lawsuit against Monsanto for damages and additional funding to move the contaminated material to a disposal site outside of Massachusetts.[90, 93] The case abstract argues that the EPA had no choice but to agree to General Electric's choice to site the landfill in Lee, despite peer-reviewed conclusions provided by the US EPA that suggested against using the Lee site, because GE had convinced the Environmental Appeals Board than an out-of-state location was too costly.[93] Similarly, Lee was left with no choice but to accept the partial settlement because otherwise GE would have refused to remove the PCBs from the river and surrounding communities.[93] Furthermore, the US EPA estimated that the removal and transport of the contaminated materials to Lee would take thirteen years to complete.[93] The filing also cites plant manager Ed Bates' estimate that approximately half a million pounds of PCB material were disposed of in the river, which contradicts the US EPA and General Electric's 1988 figure of approximately 40,000 pounds.[93] In 2022, the US EPA revised their 1988 estimate, declaring that between 100,000 and 600,000 pounds of PCB material remain in the river.[99]

While the Lee Board of Health evaluated expert testimony[100] and was unable to conclude an increased risk of health impacts stemming from the landfill's presence, elements of the plan remain unclear. These include the potential impact of airborne PCB congeners on abutters, the placement of soil containing 25-50 ppm of PCBs in Lee that will remain there for decades, and the potential for contaminants to breach or leak from the site.[17, 40, 68] Although the landfill is being designed with two low-permeability liner systems with drainage layers and low-permeability layers,[101] concerns surrounding PCB landfill leakage are rooted in historical precedent. Siting landfills in settled areas has posed long-term threats to both human and environmental health.[68, 69, 102, 103]

Case Example - Warren County, North Carolina

The Warren County PCB landfill in North Carolina was the site a large PCB contamination incident that occurred in the late 1970s, around the time that the use and manufacture of PCB containing compounds was being outlawed in the United States.[104, 105] The landfill was created in 1978 to hold soil that was contaminated after Robert Burns, an associate of the Ward PCB Transformer Company of Raleigh, and his sons deliberately "dripped" 31,000 gallons of PCB transformer oil along 240 miles of highway shoulder spanning fourteen counties.[104] Ward was instructed to take the oil to an authorized and permitted recycling facility but dumped the oil to reduce expenses and circumvent the new EPA regulations.[104, 105] State and federal authorities quickly became aware of the contaminated highway shoulders and scrambled to permit a PCB landfill in nearby rural Warren County, North Carolina.[102] At the time the landfill was proposed, 69% of county residents identified as non-white and 20% lived below the federal poverty line.[69, 102] Residents strongly opposed the construction of the landfill in their county, in what was one of the first cases of the environmental justice movement in the United States. The US

EPA and state officials offered concessions by claiming the landfill would be "state of the art," "dry tomb," and have zero percent discharge.[69]

The landfill site selection was not based on scientific or agronomic reasoning; soil permeability and the site's proximity to groundwater and private aquifers were inadequate to support the landfill.[106] Within months of burying the PCBs, the EPA found significant air contamination within a half mile of the landfill, since no leachate system was constructed to pump out contaminated groundwater; instead, the contaminated water had been leaking from the site after rainfall. 60,000 tons of PCB material was buried within seven feet of groundwater.[102, 106] In 1993, the condition of the landfill had deteriorated to the point of emergency when nearly one million gallons of contaminated water threatened to breach the liner.[103] Citizens established a five-point framework to decontaminate the site, which state officials agreed to, and the detoxification process began in the early 2000s.[103, 106] By 2004, based catalyzed decomposition of soils had been completed and, as of 2023, PCB soil levels at the site are well below EPA threshold levels.[102, 107] Officials noted that historical records quantifying contamination adjacent to the site, or the highway shoulders where the material was originally dumped, are difficult to obtain or nonexistent.[107] Furthermore, many in Warren County rely on private drinking water wells, and PCB sampling has been limited to soils, meaning these aquifers may still be contaminated.[107]

Case Example - Kettleman City, California

Kettleman City, California – like other localities in which PCB dumps were established – is home to a significant low-income and minority environmental justice population.[108] In 1982, Chemical Waste Management, Inc. (a subsidiary of Waste Management) received a Class I waste disposal permit which allowed for nearly any kind of waste, including PCBs, to be disposed of on-site.[109] The establishment of this facility was largely unknown to residents of Kettleman City.[70] In 1988, Greenpeace received a report that Chemical Waste Management was planning to install a waste incinerator to the facility, which sparked concern from residents. Soon after, a robust environmental justice movement arose in Kettleman City;[109] in 1989 residents filed a lawsuit against Chemical Waste Management to halt the construction of the incinerator.[70] Although Chemical Waste Management appealed the lawsuit, the firm dropped the incinerator plans before a verdict had been reached.[68]

Although advocates successfully blocked the incinerator from being built, the waste facility continued operating through the 1990s.[111] During this time, the US EPA and the Toxic Substances Control Act (TSCA) Enforcement Committee began scrutinizing the operations of the facility.[112] A report from the US EPA notes that environmental violations occurred annually at the facility between 1990 and 1995, and in 1998.[112] A 2004 TSCA compliance audit concluded that there had been no monitoring of certain PCBs in the facility since 1995, sixteen hazardous waste spills had occurred between 2002 and 2003, as well as six instances of hazardous wastes being stored in unsealed vessels.[109] The facility had also been approved for several permit expansions in the mid-2000s.[109]

In 2009, environmental activism in Kettleman City resurged after Greenaction, an environmental watchdog group, published a report indicating that fourteen birth defects had been reported in the vicinity of the facility between 2007 and 2008.[113] State and county public health officials, however, could not definitively link the cluster of birth defects to the operation of the facility, citing a small sample size and the inability to locate significant sources of environmental exposure in the city.[109] The facility continued to operate and received a permit in 2013 to expand its capacity.[114] That same year, the facility's operator was fined for failing to report over 70 toxic waste spills at the site.[114] Despite legal appeals from activist groups, the facility continues to operate.[108, 115]

Conclusions

Prior cases of leaks from and failures of PCB-containing landfills demonstrate that merely containing contaminated material *in-situ* may pose risks to the health, safety, and welfare of abutters and the community at-large. In particular, the operation of these facilities in densely settled urban areas, such as Kettleman City or Pittsfield, may present health risks to a significant number of residents. In addition to the proposed landfill in Lee, the Hill 78 and Building 71 containment sites remain in Pittsfield.[28] The Kettleman City and Warren County contamination incidents highlight the risks inherent to storing, rather than remediating, large quantities of toxic wastes. Although construction of these sites was permitted and authorized by local, state, and federal regulatory bodies, negligence and failures in oversight, and environmental impacts to the integrity of the sites persisted.[106, 109] Like the Kettleman City site, inspection and monitoring of the OPCA sites is delegated to the responsible party (in Pittsfield, General Electric).[28] The Kettleman City case provides an example of how this system of third-party monitoring can fail. This potential for leakage of contaminated material, and the potential for failures in monitoring and compliance, demonstrates that the implementation of technologies that remediate, rather than contain, contaminated soil should be considered. Furthermore, novel and pilot remediation technologies are given expressly stated preference under CERCLA Section 9621(b), and future remediation activity should adhere to these standards and best practices.[91]

REVIEW OF POTENTIAL REMEDIATION TECHNOLOGIES

Numerous established and novel technologies exist to remediate PCB contamination *in-situ* (on-site), which would limit the need to transport and contain contaminated material in landfills or disposal facilities.[116] These technologies are diverse in process and scope, meaning that they are applicable to various environments with varying levels of contamination.[116] Some of these technologies, such as phytoremediation, rhizoremediation, and bioretention, utilize the inherent ability of some plant and microorganism species to metabolize and degrade PCBs in soils and groundwater.[117] Others, such as activated carbon, sequester contaminants in the sediments of aqueous environments which reduces their bioavailability.[118] Lastly, engineering-based solutions such as *in-situ* chemical oxidation (ISCO) use pump systems to inject chemical oxidants into the earth that react with and break down contaminants into less harmful substances.[43, 119] The methods outlined below have been highlighted for their applicability to the chosen contaminated sites in Pittsfield. In addition, these methods attempt to strike a balance between the success of outcomes, safety, and potential impacts to the natural environment.

Phytoremediation

Phytoremediation refers to the use of plants to biodegrade organic pollutants in soils, sediment, and groundwater.[117] Plants uptake contaminants through their roots, and then transform them through enzymes or direct volatilization into the atmosphere.[120] Phytoremediation is an environmentally friendly, low-tech, and low cost means of removing contaminants from the environment and has no impacts on soil fertility or structure; in fact, phytoremediation can improve overall soil health since plants introduce nutrients, minerals, and aid in erosion control.[121, 122, 123]

Ideal plants for use in phytoremediation are those that have high tolerance to contaminants, broad root distribution, and high biomass production.[121] Microorganisms play a role in phytoremediation through the associated microbial processes of rhizoremediation and rhizodegradation.[124] A distributed network of plant roots can activate these microbial processes, which are also effective at removing PCB contamination from soils.[124] Plant roots can release microbial growth factors, extracellular enzymes, or acids that facilitate microbial metabolism or serve as electron donors for anaerobic contaminant degradation processes.[123, 125] The use of native plant species is recommended to avoid the spread of invasive species and for beneficial interaction with local fauna.[126]

Bioretention Areas and Bioswales

Bioretention areas (also known as “rain gardens”) and bioswales are engineered, landscaped, “green” stormwater management and treatment structures.[127] A bioretention area is a shallow depression filled with a layer of sandy soil topped with a layer of mulch or wood chips, and then densely planted with vegetation.[127] Stormwater runoff flows into the cell and filters through the soil and into the groundwater; some of the runoff is also taken up by the plantings.[127] Bioretention areas are designed to allow 6-8 inches of ponded water; if fast drainage is required, a perforated underdrain may be used that connects to the storm drain system.[128] They can be used and constructed at a wide range of sites with varied climactic and geologic settings and can be flexibly sized to suit dimensional and areal constraints.[128] Bioretention areas effectively remove pollutants through filtration, rhizodegradation, and phytodegradation.[127] They are low-tech, affordable, easy to install, and increase groundwater recharge.[127] When selecting plants for bioretention areas, discretion can be taken to choose native species that are effective at remediating PCBs.[129] *Sparganium* (bur-reed) promotes oxidation of low-chlorinated PCB congeners, while *Panicum virgatum* (switchgrass) have been shown to degrade both low-chlorinated and high-chlorinated PCB congeners.[129] Both species are native to and widespread in the northeastern United States.[130]

When remediating stormwater "hotspots" with high pollutant loads, designs should incorporate pretreatment infrastructure or an impermeable underdrain to carry infiltrated water to an offsite treatment location prior to discharge.[128] Bioswales and filter strips are commonly used in conjunction with bioretention areas as a pretreatment mechanism.[127] Bioswales are open, linear, vegetated channels that convey stormwater and offer some pretreatment and infiltration benefits.[131] They are often integrated into roadway medians, parking lots, or along the shoulders of roadways.[131] In well-drained areas, ditch blocks or weirs perpendicular to the flow path can be placed to capture small volumes of water and allow for some pretreatment and infiltration.[132] Like bioretention areas, bioswales are low tech and cost-effective to construct and maintain.[132] PCB remediating plants like *P. virgatum* and *Sparganium* can also be used for vegetation in bioswales.[133]

Hybrid or Conventional Poplar Farms

Poplar trees (genus *Populus*) have long been popular in phytoremediation applications because they are ideally suited for it; their deep, extensive root systems and quick growth allow them to rapidly and effectively uptake and metabolize a wide range of environmental contaminants.[134] Since poplars are large deciduous trees, they have much greater capacity to uptake contaminants and water than grasses and shrubs while providing added erosion control and soil health benefits.[134] In recent years, hybridized and transgenic varieties of poplar have been developed to metabolize a wide range of organic pollutants more effectively, including PCBs.[135, 136]

In Apulia, Italy (a region with several PCB-contaminated brownfield sites), an experimental farming initiative using 650 plantings of the Monviso poplar cultivar was launched in 2013.[136] The site contained high levels of both PCB and heavy metal pollution.[136] 900 days after planting, soil analysis revealed that soil PCB concentrations in all samples were below the Italian legal limit of 60ng/g.[136] The trees grew healthily in the contaminated soil, and results suggest that the poplars were effective at promoting PCB rhizodegradation; organic carbon content in the rhizosphere increased dramatically adjacent to the planted plots, and microbiological analysis revealed overall increases in microbial abundance, cell viability, and bacterial groups involved in PCB rhizodegradation.[136] Therefore, the plantings simultaneously aided in restoring soil health.[136]

In the United States, poplar farming has become a widespread means of decontaminating brownfield sites in the Great Lakes Region.[135] The use of the technique has been popularized primarily through word-of-mouth and through research conducted at the University of Minnesota on hybridized and transgenic poplar cultivars.[135] The InnovaTree, a patented hybrid poplar developed at the Natural Resources Research Institute of the University of Minnesota in collaboration with the USDA Forest Service, has been deployed at sixteen sites with over 20,000 individual plantings.[135] The InnovaTree can grow at a rate fifty times faster than conventional poplars, increasing its potential to take up and remediate pollutants.[135] They are also “geo-robust,” meaning they can grow and thrive in a wide range of climate types and conditions.[135] The InnovaTree was licensed for commercial sale in spring 2023.[135] Planting and harvesting poplar trees for phytoremediation also provides secondary benefits to the local economy, through job creation in the agroforestry sector.[135] After remediation is complete, the trees are harvested for use in bioenergy production, lumber, paper, or other applications.[135]

Activated Carbon

Activated carbon is a form of processed carbon that is commonly used to remove contaminants from air and water.[118] The carbon is processed to create small pores that increase its surface area available for adsorption and chemical reactions.[137] Because of the microporosity of activated carbon, one gram of material can have a surface area of greater than 32,000 sq ft.[137] Activated carbon has been widely and effectively applied in the remediation of PCB-contaminated sediment and waterbodies.[138, 139, 140] Applying activated carbon to sediments and soil enhances PCB immobilization; the porous surface of the carbonaceous material and leads to adsorption of PCB contaminants.[116]

A pilot study at Hunters Point Shipyard in San Francisco demonstrated a 73% decrease in transfer of PCB material from sediment into the aquatic environment in a 60-day span following the application of activated carbon.[139, 141] After 18 months, aqueous PCB concentrations were reduced by 90%, suggesting the method has long-term effectiveness.[141] An additional pilot study in freshwater Lake Hartwell in South Carolina found that application of an activated carbon dose of 2% of the total dry sediment mass lowered aqueous PCB contamination by more than 95% after one month of treatment and more than 98% after six months.[138] The success of the method when applied to freshwater demonstrates that the application of activated carbon may be an effective means of remediating contaminated waterbodies in Pittsfield, particularly those that contain sensitive habitats and ecosystems to reduce or eliminate the need for the destructive action of sediment dredging.[140] The area surrounding Goodrich Pond is home to a range of species threatened in Massachusetts, meaning that the use of less habitat-intrusive methods of remediation such as activated carbon are warranted.[53]

In-Situ Chemical Oxidation (ISCO)

In-situ chemical oxidation (ISCO) is a common soil and groundwater remediation best management practice because of its efficacy.[119] ISCO works by introducing strong chemical oxidizers into contaminated medium via an injection well to break down contaminants at the source, including contaminants that are largely resistant to organic degradation, such as PCBs.[119] Common oxidizers include Fenton's reagent, potassium and sodium permanganate, ozone, and persulfate.[43, 142] The use of persulfate in ISCO applications has been growing since the 1990s because it is more stable, treats a wide range of contaminants, and is not as easily absorbed by soil as other oxidizers.[43, 143] "Persulfate ions" in environmental engineering refers to the peroxydisulfate oxyanion ($S_20_8^{-2}$), which is a constituent of the sodium persulfate salts used in environmental remediation applications.[144] Persulfate ions can be thermally activated to generate the sulfate radical SO_4^-, which has a high redox potential[j] and is an effective agent in PCB degradation.[43, 145] Heat, ultraviolet light, high pH, and other agents are typically used to activate the persulfate ions and generate sulfate radicals such as SO_4^-.[43, 142, 146]

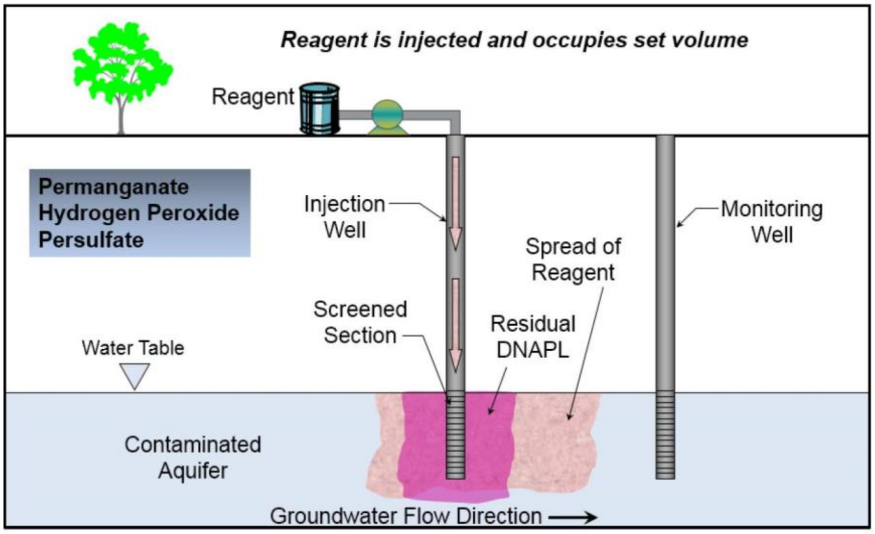

Figure 11: Diagram of ISCO injection system. Figure source: Federal Technologies Remediation Roundtable

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[j] A measure of the tendency or "easiness" of a chemical to give up or retain electrons, thereby breaking down the substance (Kansas Geological Survey n.d.).

In laboratory settings, persulfate has been demonstrated to be an effective oxidizer of PCB compounds.[43, 142, 145] A 2013 study examined the use of *in-situ* oxidation of PCB congener 2,4,4′-CB, which was completely decomposed by persulfate at a temperature of 30 degrees Celsius within eight hours.[145] The transformation pathway is divided into two steps: dechlorination and hydroxylation.[145] Sulfate radicals were predominant under acidic conditions and hydroxyl radicals (•OH) were predominant under basic conditions.[43, 145] Decreasing the pH of the solution resulted in more efficient degradation of 2,4,4′-CB.[145] While this study did not explicitly examine use of the method in targeting 3,3',5, 5'-Tetrachlorodiphenyl (Aroclor-1248) or 2,3,4,2',3',4'-Hexachlorobiphenyl (Arolcor-1260), the destruction of PCB compounds using persulfate has been determined to be non-congener-specific, meaning that the same mecahnism of degradation applies to other PCB congeners.[43, 145, 146]

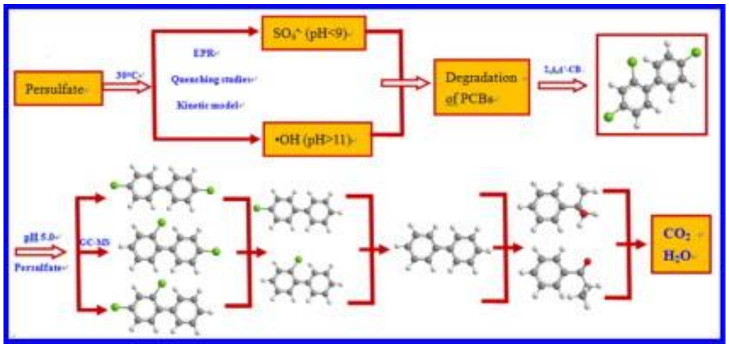

Figure 12: Oxidation of PCB with persulfate. Source: Fang et al, 2013

Furthermore, the sulfate radical is an electrophilic chemical species, meaning that it accepts electron pairs to bond to neucleophiles.[142] The effectiveness of sulfate radicals is increased in media that contains a high concentration of electron donating organic compounds.[142, 145] One of these electron donating groups present in organic compounds is hydroxyl (-OH).[142] Adding alkaline substances, such as lime, that increase the pH of the oxidizing solution can increase the production of hydroxyl free radicals.[43] Additionally, researchers have become aware of the presence of mono-hydroxylated polychlorinated biphenyls (OH-PCBs) in biota, air, and sediments.[38] While the origin of OH-PCBs remains poorly understood, they are likely produced in the environment from existing high-chlorine PCB contaminants by a combination of biological metabolism, atmospheric reaction, and oxidation ocurring during municipal wastewater treatment.[38] The toxicity profile of OH-PCBs differs slightly from other congeners; they are known to be estrogen receptor agonists and antagonists, and increased OH-PCB levels in the body is also associated with decreased thyroid hormone levels.[38, 39] OH-PCBs can also be metabolized into carcinogenic PCB quinones.[38, 39] Many OH-PCB congeners (varieties of PCBs that have had a hydroxyl group, “OH,” introduced via natural oxidation processes) are vapor phase PCBs like those identified in Pittsfield’s Lakewood neighborhood.[17, 38] While the extent of OH-PCB contamination in sediments and the environment is poorly understood, OH-PCBs have been identified in sediments at numerous contaminated sites with distinct environmental conditions.[147] This suggests that their presence is widespread.[147] Because sulfate radicals are electrophilic, there is strong potential for effective PCB degradation at sites with quantities of hydroxylated PCBs.[43]

Remediation strategies effective against these airborne, volatilized PCB congeners, such as ISCO, are essential to protect the health of the community and its food systems. Because ISCO-based remediation of PCBs is not congener-specific[146] and because the presence of increased hydroxyls (the OH in OH-PCBs) is associated with more effective oxidation of contaminants, this method may be effective in oxidizing these volatile PCB congenners.[43, 142] Traditional institutional controls, such as fish consumption bans, are ineffective given the airborne nature of these congeners.[21] Although hydroxylated PCBs are an emerging risk, and there are limited studies assessing their characteristics and toxicity, evience suggests that they are also endocrine disruptors, are associated with similar human health impacts, and that these toxic effects can occur with lower doses.[38, 39] Given the presence of these compounds in the Lakewood neighborhood,[17] ISCO-based efforts to remediate the soil containing these compounds should be considered.

DISCUSSION AND SITE-SPECIFIC RECOMMENDATIONS

Goodrich Pond

Restoration of Goodrich Pond should consist of a three-fold process to address the identified sources and routes of contamination; remediation of the soils and sediments of the pond itself to prevent consumption of PCB-containing food sources by fish, remediation of the banks of the pond, and measures to prevent contaminated fish from entering the pond from the Housatonic River.

Remedial Action	***Intent of Activity***
Phase 1: Thin-layer capping of pond soils and sediments with activated carbon	Prevent the spread of PCBs from pond sediments into the water and the food chain. Reduces the bioavailability of PCBs to aquatic organisms.
Phase 2: Targeted bioremediation of bank soils	Remove PCB contamination remaining in soils in the immediate vicinity of the pond.
Phase 3: Installation of passive mesh screen fish barrier	Prevent potentially contaminated fish from entering the pond from the Housatonic River, as identified in the 2001 DPH assessment.

Figure 13: Summary of recommended remedial activities of Goodrich Pond.

Phase 1: Thin-Layer Capping of Pond Soils and Sediments with Granular Activated Carbon (GAC)

Two forms of activated carbon, granular activated carbon (GAC) and powdered activated carbon (PAC) are commonly used in liquid-phase remediation of contaminated sediments.[24] GAC and PAC exhibit different physical properties and induce different biological responses in aquatic macroinvertebrates (worms and other similar organisms).[148, 149] Individual PAC grains are typically less than 300 μm in size, while GAC grains are larger than 300 μm.[148] Because of its small size, PAC can be ingested by some species of aquatic macroinvertebrates which is associated with reduced weight and carbon assimilation.[148] Conversely, the application of non-ingestible GAC was associated with increased weight and carbon assimilation in aquatic worms.[148] Additionally, the use of PAC was found to be more disruptive towards aquatic microbiota than GAC, by significantly altering the pH of the waterbody.[148, 149] At the time of writing, there are scant peer-reviewed studies assessing the impacts of GAC and PAC on aquatic organisms when applied as a remediation or wastewater treatment technique; however, the existing literature suggests that GAC poses fewer risks to aquatic macroinvertebrate species.[148, 149, 150] Furthermore, GAC and PAC further differ in terms of efficacy and persistence in waterbodies.[148] PAC is thought to sequester PCBs and PAHs more effectively in the short term but is readily disrupted and resuspended in turbulent water; conversely, GAC is slower acting but is more persistent and tends to remain on the sediment surface.[148]

The persistency, effectiveness, and reduced ecological impact of GAC when compared to PAC render it a favorable candidate for application to Goodrich Pond sediment.[148, 149, 150] Activated carbon can be applied directly to waterbodies without requiring sediment removal or dredging.[148] Dredging is commonly used to remediate highly contaminated waterbodies, but often significantly disrupts sensitive aquatic habitats.[140, 151] Instead, GAC can be mixed directly into local clays and sediments to form a thin-layer cap or permeable reactive barrier that sequesters contaminants and reduces the bioavailability of PCBs.[148, 152] This cap is placed on top of the contaminated subsurface.[153] GAC thin-layer capping is a relatively new method of in-situ remediation, and several field trials have demonstrated between 60-99% reductions in PCB contents in biota, groundwater, and sediment-to-water mass transfer.[150, 153] With the low level of PCB contamination the Goodrich Pond sediment and the ecological sensitivity of the pond, thin-layer sediment capping with GAC presents a less disruptive, yet effective, alternative to dredging.

Phase 2: Targeted Bioremediation of Bank Soils

Remediating non-liquid-phase contaminated areas of the pond, such as its banks and abutting contaminated land, could occur through phytoremediation. Many factors, such as the characteristics of the targeted contaminant (PCBs), plant and microbial metabolic mechanisms, and the ability of plants to enzymatically transform the contaminant must be considered for bioremediation to be successful.[117] Although investment in phytoremediation programs has increased sixfold since the 1990s and phytoremediation has been shown to effectively reduce the hazards of organic and inorganic pollutants, the use of conventional plants and plant-associated bacteria is inherently limiting.[117] Unmodified plants and bacteria lack the enzymes necessary to fully metabolize organic compounds such as PCBs and consequently, the use of conventional plants may result in incomplete remediation.[117, 154]

PCBs are quite hydrophobic and chemically stable, meaning that degradation and transformation of PCBs by plants and their associated bacteria occurs slowly.[117] Despite these shortcomings of PCB phytoremediation using conventional plants, studies have yielded somewhat promising results.[155, 156, 157, 158, 159] Because PCBs are poorly taken up inside plant tissue, microbial rhizoremediation methods have been the most successful.[117] In rhizoremediation, the root systems of plants release microbial growth factors, extracellular enzymes, or acids that facilitate microbial metabolism or serve as electron donors for anaerobic contaminant degradation processes.[123, 125] Additionally, roots release organic molecules that act as natural surfactants; this mobilizes PCBs and increases their susceptibility to plant tissue absorption.[117]

Rhizoremediation studies of soils contaminated with Aroclor-1242, Aroclor-1248, and Aroclor-1260 found that planted soils exhibited higher mineralization and removal of PCBs than unplanted control soils.[155, 156, 157] Tall fescue (*Festuca arundinacea*), black mustard (*Brassica nigra*), alfalfa (*Medicago sativa*), deertongue grass (*Dicanthelium clandestinum*), and switchgrass (*Panicum virgatum*) were shown to increase oxygen diffusion and microbial enrichment in soils and were associated with mineralization of PCBs.[156, 157] Still, these field trial degradation rates were rather slow, potentially resulting in accumulation of toxic compounds in soils.[117, 156, 157]

To address the shortcomings of bioremediation using conventional plant species, researchers have begun to develop and implement bioengineered (transgenic) plants for more effective bioremediation of PCBs.[117, 135, 160] Transgenic plants are engineered to compensate for the shortcomings inherent to bioremediation using conventional plants and can target specific pollutants.[161] Development of these plants can occur by introducing external genes with products involved in detoxification processes into the plants themselves, or into root colonizing bacteria.[162] Typically, these genes are derived from microbial and mammalian sources, as these organisms may possess catabolic enzymes that can achieve near-complete mineralization of organic molecules.[117, 154]

Alfalfa (*Medicago sativa*) and willow (*Salix*) are two host species that have been studied for PCB bioremediation.[117] Genes encoding biphenyl 2,3-dioxygenase, an enzyme that catalyzes the first step of the biphenyl degradation pathway, were introduced into the alfalfa root colonizing strain *Pseudomonas fluorescens* F113.[163] Similar methods were applied when introduced to the *Salix* root colonizing strains.[164] In both studies, inoculation of the rhizosphere (the soil region influenced by root secretions and associated microorganisms) with the engineered bacteria was successful.[163, 164, 165] An additional field study using transgenic alfalfa plants expressing the *bphC* gene, which encodes enzymes associated with PCB degradation, demonstrated that these transgenic alfalfa plants were effective and have significant application potential in in remediation of PCBs.[166]

Despite the successful bioremediation performance of transgenic alfalfa plants in small-scale trials, their use in site remediation is limited by a relatively small body of research and a lack of commercial availability.[116, 117, 135] Locations in the vicinity of Goodrich Pond may be suitable for small-scale bioremediation field trials using transgenic alfalfa or other plants.[117] Additional evaluation and sampling of bank soils is warranted to identify locations where PCB contamination exceeds the regulatory threshold concentration of 2 ppm.[77] Parcel K9-1-33, the location where some soil samples were found to contain as much as 2.5 ppm of PCBs, may be a promising site for plantings.[77] While there are inherent shortcomings to the use of bioremediation in PCB contaminated soil, its relatively low cost and ease of implementation make the use of transgenic plants a promising remediation strategy in the coming years. Additionally, phytoremediation is a low-impact, minimally disruptive remediation technique[117, 159] that aligns with the goals of CERCLA section 9621(b) to promote the use of technologies that remediate, rather than transport or dispose of contaminated material.[91] The recent developments of novel transgenic plants designed to target PCB contamination, coupled with the recent appeals of the consent decree to remove contaminated materials to the Lee landfill, presents an opportune moment to conduct pilot field studies of this technology in Pittsfield.[93, 117, 159, 160]

Phase 3: Traditional Passive Mesh Screen to Prevent the Intrusion of Contaminated Riverine Fish

In addition to direct remediation of the pond itself, measures should be taken to limit the spread of contaminated fish into the pond from the Housatonic River.[78] The pond is connected to the river via an approximately 12-foot-wide intermittent stream.[47, 167] Numerous methods exist to exclude fish from waterbodies, but the traditional passive mesh screen is one of the most common and simple fish exclusion devices.[45] A passive mesh screen consists of a series of mesh panels inserted into a metal frame that spans the length of the stream and can be configured to suit any size waterbody.[45] Commonly, the metal frame includes an overhead walkway and lifting gear to facilitate cleaning and maintenance of the panels.[45, 168] The mesh can exclude all fish species at any life stage; however, the National Marine Fisheries Service (NMFS) and state regulatory agencies impose specific design criteria for passive mesh screens to limit harm to fish.[168, 169]

In accordance with NMFS guidelines, the approach velocity of flow entering the screen must not exceed 0.20 ft/s for passive mesh screens.[45] Regarding mesh aperture, 3/32-inch openings are a maximum allowable size established by various regulatory bodies, including the NMFS, the National Oceanic and Atmospheric Administration (NOAA), and the Washington Department of Fish and Wildlife.[45, 170, 171] This aperture size is designed to limit damage to fish fry.[170, 171, 172] In areas where there is potential damage from floating debris, such as the Housatonic River, the minimum recommended mesh diameter is 0.80 inches (14 gauge).[170] The screen would be installed across the intermittent stream at the confluence of the stream and the Housatonic River. Design guidance suggests that the screen should be installed to be flush with the riverbank.[168] Further investigation of stream flow and dimensions is warranted to design and implement a fish screen; these measurements could not yet be taken. However, passive mesh screens are a historically successful method of fish exclusion, and the installation of this screen should be considered to exclude contaminated river fish from Goodrich Pond.

Figure 14: A passive mesh screen in Devon, UK. Source: United Kingdom Environment Agency.

Limitations and Conclusion

Precise study of the sizing and design of the passive mesh screen was limited by the difficult accessibility of the waterbodies and the seasonality of the stream. Additionally, the report on soil and sediment contamination in Goodrich Pond provided by MassDEP references further study of several parcels adjacent to the pond; however, it could not be determined whether these studies were conducted. Nevertheless, it is apparent that PCB contamination in Goodrich Pond stems from multiple sources, and consequently, a multi-method approach must be taken to completely remediate the pond and the land adjacent to it.[76, 77] As of this writing, remediation of the pond itself and much of its immediate vicinity has not yet occurred,[52] likely due to the relatively low levels of PCBs remaining in the pond and the limited public health implications of its contamination when compared to other sites in Pittsfield.[76, 77] These characteristics of Goodrich Pond, however, render it a promising location for the use of emerging remediation methods, including phytoremediation and rhizoremediation with or without the use of transgenic plants.

Hill 78 and Building 71 On-Plant Consolidation Areas (OPCAs)

Analysis of the existing conditions in the OPCAs revealed that these landfills hold very high concentrations of PCB-contaminated material (>50ppm at the Building 71 site), within a clearly defined and compact area.[28] Although these landfills are capped and secured, the storage of high-concentrations of PCB-contaminated landfill waste near an urban residential neighborhood poses inherent risks.[103, 110] For these reasons, this thesis proposes a multi-stage *in-situ* remediation process employing an initial treatment of persulfate-based *in-situ* chemical oxidation, followed by the restoration of remaining soils with the installation of a bioremediating trees and grasses. This method aims to remediate the contamination at its source, rather than merely store the material.

Remedial Action	***Intent of Activity***
<u>Phase 1:</u> Aggressive remediation of landfill sites using persulfate *in-situ* chemical oxidation (ISCO)	Eliminate PCB contamination from the current landfill site, without the use of excavation and removal to a different site. Mitigate risks associated with the storage of PCBs in a landfill.
<u>Phase 2:</u> Bioremediation “top off” using a poplar tree farm and the construction of vegetated bioretention areas	Remediate trace amounts of PCBs that may remain after ISCO treatment using a low-impact, green method. Prevent the potential runoff of ISCO byproducts and PCB contaminants from the site into adjacent soil and groundwater. Restore soil quality of the site following ISCO treatment and mitigate erosion.

Figure 15: Summary of proposed remedial activities at the Hill 78 and Building 71 site.

Phase 1: In-Situ Chemical Oxidation (ISCO)

ISCO is an aggressive remediation technique, and a comprehensive analysis of the dense non-aqueous phase liquid (DNAPL) contamination zone[k], including an assessment of soil, hydrologic characteristics, and the depth and spread of contamination, is warranted prior to beginning treatment.[43, 172] This includes an EPA method 8082 test (PCB by gas chromatography)[l] to estimate contaminant mass/location, determine baseline levels, and evaluate treatment effectiveness following injections.[43, 173] These assessments fall outside the scope of this work; however, a review of existing literature assessing site conditions and the technical recommendations for ISCO treatment provide insight into its applicability at the OPCA sites.[28, 43, 44, 48] The remainder of this section provides a framework for ISCO remediation of the site under the assumption that it is applicable. If it is not, the following recommendations for a novel two-step remediation method using chemical and nature-based technologies may be insightful for remediating other ISCO-suitable sites of PCB contamination.

PCBs are classified as DNAPLs, aqueous contaminants that are denser than water (Aroclors have a relative density of 1.5) and non-water soluble.[172, 174] DNAPLs present distinct needs and challenges for ISCO remediation that contrast with LNAPLs, or light non-aqueous phase liquids.[175, 176] Because LNAPLs are less dense than water, infiltration

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[k] The DNAPL zone refers to the area of materials inside the Hill 78 and Building 71 containment areas that contain PCBs.[172]

[l] A precise method for analyzing a complex mixture of compounds.[197, 198] The sample is typically dissolved or diluted using a solvent and then injected into the hot inlet of the gas chromatograph (GC), where it is vaporized and becomes a gas.[197] An inert gas, such as helium, carries the vaporized sample into the column; different substances within the gaseous sample react differently with the inert gas, which separates these substances by causing them to travel through the column at different speeds.[197] The separated gases enter a detector, usually a mass spectrometer, which identifies and separates compounds by their distinct masses.[197, 198] Finally, the GC produces a chromatogram, a peaked graph. The size of the peaks indicates the amount of the compound detected in the sample.[197, 198]

stops at the water table, are typically contained within a smaller location, and therefore are less expensive and easier to locate and remediate.[175] Conversely, DNAPLs tend to sink deep into soils well below the water table and only stop when reaching impermeable bedrock.[176] Due to the depths and dispersibility of DNAPLs, excavation and removal is not always practicable.[177] This leaves containment (the current method) or *in-situ* dechlorination methods as the applicable technologies.[177]

PCBs are notoriously difficult compounds to remediate and require specific conditions for chemical oxidants to activate and react with the PCBs.[178] As previously mentioned, an ISCO method using a combination of sodium persulfate, lime, and thermal activation is most promising.[43, 44] This decomposition of reaction of persulfate in an alkaline solution is shown below, yielding hydrogen sulfate, sulfate radicals, and oxygen:[43]

$$S_2O_8^{2-} + OH^- \rightarrow HSO_4^- + SO_4^{2-} + \tfrac{1}{2}O_2$$

The addition of lime increases the pH of the solution; theoretically, an alkaline solution should lead to increased production of hydroxyl (OH^-) free radicals through the reaction of OH^- and the added radicals.[43, 142, 145] Laboratory testing has shown that adding lime generates additional hydroxyl ions – the thermal activation of the persulfate aids in the formation of additional sulfate free radicals.[44, 142, 179] The formation of these multiple radicals has been shown to be highly effective at destroying recalcitrant compounds, including PCBs.[43]

In the field, Klozur – a proprietary activated persulfate compound for use in ISCO applications – has been demonstrated to be effective at remediating PCB-contaminated soil.[146, 180] Injection of Klozur into contaminated soils is also thought to not lead to intermediate dioxin production as a byproduct of oxidation.[146] However, the application of Klozur or similar persulfate oxidizers outside of laboratory settings requires distinct methods of injection to be maximally effective.[180] Since PCBs have low water solubility and high absorbance to soils, the majority of PCBs are found in the saturated and vadose zones of the subsurface;[181] however, the persulfate oxidation reaction ideally takes place in the aqueous phase.[43] Therefore, specific *in-situ* or *ex-situ* methods that increase soil permeability must be used when injecting the oxidant into the contaminated medium.[146]

Oxidizing solutions are typically applied on-site using injection wells or injection probes.[182] Injection wells consist of a hollow metal rod hammered into the ground, or by injecting the oxidant into wells using an auger or rotary drilling.[182] Typically, a pilot study is conducted to determine appropriate spacing and placement.[183] An injection probe is like an injection well but is better suited for use in areas with low-permeability soils.[182] The injection probe, a perforated narrow-aperture metal tube, is inserted into the ground and the oxidants are pumped into it at a low pressure.[184] The oxidant exits the perforations and enter existing cracks and striations in the subsurface.[184] From there, the oxidant spreads through the soil and creates what is known as a "halo of reactivity."[184] Given that low-permeability urban land soils make up much of the fill in the Hill 78 and Building 71 OPCAs, the ISCO injection method must be tailored to suit these conditions.[48, 182] This means that the use of injection probes, as opposed to injection wells, would likely be more effective at introducing the oxidant into the subsurface soils.[182, 183, 184]

Depending on the permeability of material at the site, additional methods of increasing soil permeability may be required to effectively induce the oxidation reaction.[184] These methods include hydraulic fracturing (fracking), and soil mixing.[184] Hydraulic fracturing is the process of creating artificial fractures and striations in an area of low permeability.[185] Holes are drilled into the ground, and powerful jets of water are used to fracture the subsurface medium.[184, 185] These fractures are then filled with sand, which creates permeability for the oxidants to pass through.[184] Fracking, however, is a highly controversial and potentially harmful practice.[186, 187] Most public debate and research surrounding fracking concerns its applications in oil and gas extraction; however, impacts such as noise pollution and the triggering of seismic activity may be cause for concern in ISCO applications.[187] Additionally, pneumatic and hydraulic fracturing may result in the creation of pathways that allow contaminants and injected materials to flow in unintended directions.[188] Soil mixing is an alternative method recommended for persulfate application that is less disruptive and risky than fracking.[189] Soil mixing can either occur *in-situ* or *ex-situ*.[189] For contamination near the surface, conventional construction equipment (such as a bucket mixer) and soil mining equipment can be used.[184] To mix deep soils *in-situ*, oxidants are pumped to the mixing depth using piping or a drilling tool known as a Kelly bar.[184] The soil is then mixed using an auger-like device with mixing blades.[184]

Because of the risks and controversial nature of fracking, soil mixing is the preferred method of increasing soil permeability for oxidant application.[184, 188] Additionally, much of the literature surrounding ISCO treatment for PCB contamination found soil mixing to be a critical step in successfully inducing the oxidation reaction.[43, 146] Prior to initiating ISCO treatment, further study is required.[43] This includes the administration of the EPA method 8082 assessment (PCB gas chromatography) and a field analysis of soil permeability and depth of contamination.[43, 173] During treatment, monitoring, and the re-administration of the EPA method 8082 assessment is warranted to track efficacy and monitor potential risks to the environment and surrounding area.[43]

The products formed from persulfate-based ISCO treatments – mainly water, carbon dioxide, chloride, and sulfate – are relatively innocuous.[44] Persulfate based solutions are further believed to not result in intermediate dioxin production.[145, 146, 180] However, several byproducts of concern to areal hydrology and geochemistry may be formed, such as ketones.[44] In rare instances, chloromethane, methylene chloride, and trihalomethanes (THMs) have been found at sites after completion of ISCO treatment.[44] The formation of these compounds from persulfate treatment is poorly understood but are thought to result from reactions with organic matter and iron in the soil.[44] Despite the formation of these potential byproducts, ISCO largely remains a safe and effective means of remediating contaminated soil. Because of the potential for the formation of byproducts in the soil (namely THMs and ketones), this thesis recommends following the ISCO treatment with bioremediation treatments.[44, 190] Coupling ISCO with secondary treatments, including intrinsic and enhanced bioremediation, is often used as part of a comprehensive treatment approach at contaminated sites.[190]

Phase 2: Bioremediation

Phase 2 of the OPCA remediation initiative incorporates nature-based methods to restore soil quality and remediate byproducts of the ISCO treatment, in addition to residual PCB contamination remaining on-site. Although bioremediation is often used as a contaminant mass reduction process prior to an ISCO treatment, applying this method after ISCO treatment may avoid some of the drawbacks associated with pretreatment.[44, 190] Pretreatment bioremediation may reduce anaerobic soil conditions and create elevated biomass concentrations in the treatment zone, thus leading to competition and reducing the efficacy of the oxidant.[190] Additionally, post-ISCO bioremediation may aid in soil restoration and erosion control.[136] The bioremediation framework includes the installation of a poplar tree farm, in addition to a peripheral bioretention area consisting of grasses and flowering plants with demonstrated phytoremediation applicability.

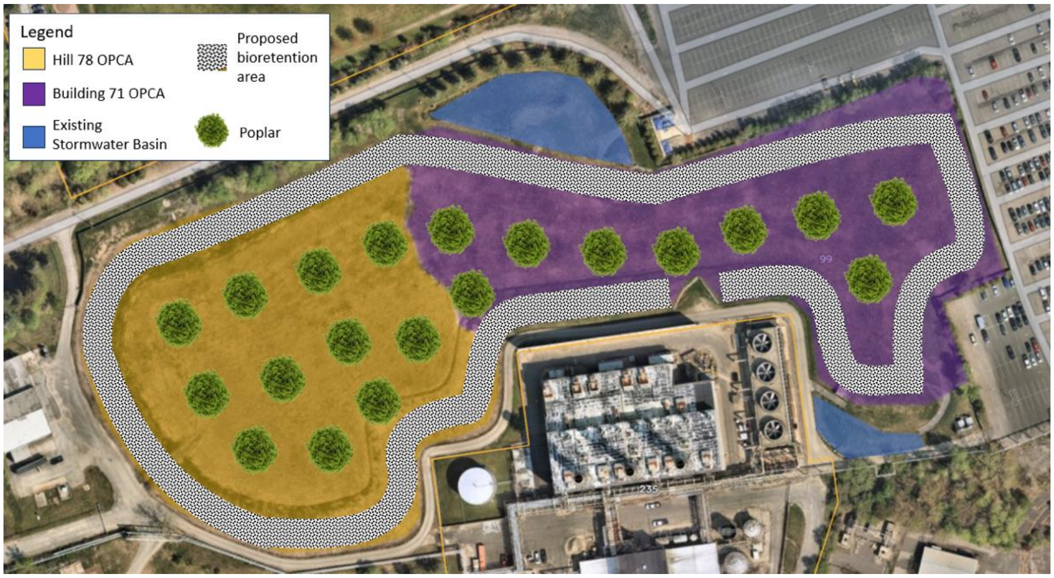

Figure 16: A rendering of a potential bioremediation plan for the Hill 78 and Building 71 OPCAs. Note: tree placement is illustrative and not to scale.

The figure above depicts an aerial view of the Hill 78 and Building 71 OPCAs, showing existing conditions and infrastructure, along with the proposed bioremediation initiative. The Hill 78 and Building 71 sites rise approximately 15 to 20 feet above the surrounding land and are encircled by a ring of flat to slightly depressed earth that measures approximately 50 feet in width.[28, 47] The proposed design suggests the planting of poplar trees throughout the elevated portions of the OPCAs, with a vegetated bioretention area constructed in the depressed area surrounding the sites. The poplar tree plantings would restore, remediate, and prevent erosion of the post-treatment soils, and the bioretention barrier is designed to capture and treat any stormwater runoff that flows off the hill.[127, 128, 136] Constructing this barrier would augment the existing on-site stormwater basins and allow for increased capture and treatment of runoff.[127, 128]

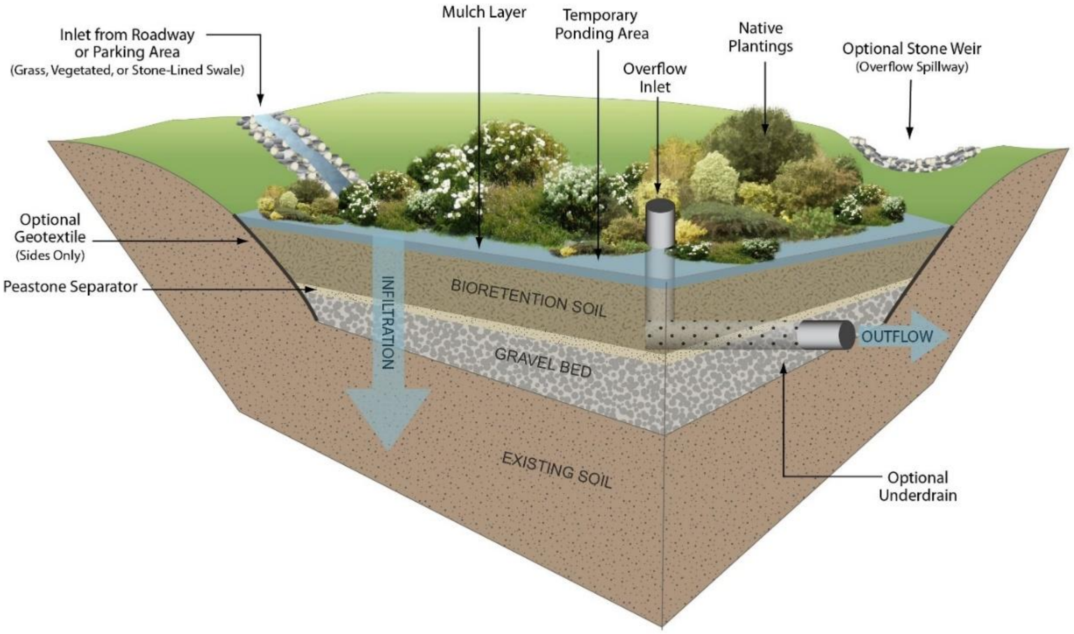

Figure 17: Diagram of a bioretention area. Source: Massachusetts Clean Water Toolkit.

Bioretention areas typically incorporate several key elements designed to facilitate the infiltration and treatment of stormwater runoff.[127, 128] The bioretention area consists of a shallow depression that is filled with several layers of material.[128] The uppermost layer consists of sandy recharge-type soils, followed by a pea stone separator that allows the soil to remain firm and the bottom layer of gravel beneath porous.[191] Below the gravel is the existing on-site soil. The top layer of bioretention soil is planted with selected water-tolerant vegetation, as stormwater temporarily ponds in the bioretention area during treatment.[127, 191] In the event of excessive amounts of water entering the bioretention area, an overflow inlet (a pipe) channels the excess water out via an underdrain.[127]

Prior to entering the bioretention area, stormwater is pre-treated using a series of sediment forebays.[127] These consist of an excavated pit combined with a weir.[192] The purpose of the forebay is to slow the velocity of incoming stormwater and facilitate the separation of suspended solids prior to entering the bioretention area.[192] Sediment forebays are easily accessible and cleanable for sediment removal, prevent the bioretention area from becoming clogged with sediment, and moderate the flow of stormwater entering the bioretention area.[127, 192] In Massachusetts, MassDEP regulations require the construction of a sediment forebay as a pretreatment device for stormwater discharge into a bioretention area or comparable device.[127]

Figure 18: A sediment forebay. Source: Massachusetts Clean Water Toolkit.

Plant selection and the principles of phytoremediation for designing the bioretention area largely follow those proposed for the remediation of Goodrich Pond. A mix of transgenic and native plants with the potential to metabolize PCBs and other stormwater contaminants would be installed. These include tall fescue (*Festuca arundinacea*), black mustard (*Brassica nigra*), alfalfa (*Medicago sativa*), deertongue grass (*Dicanthelium clandestinum*), and switchgrass (*Panicum virgatum*).[156, 157]

The remainder of the site, consisting of the landfill hills encircled by the bioretention area, would consist of a tree farm with plantings of conventional or transgenic InnovaTree poplars.[135] Field and laboratory studies of both conventional and transgenic poplars have demonstrated efficacy at remediating PCB contamination, in addition to a range of organic and inorganic soil contaminants.[134, 135, 136] Following successful ISCO treatment, the concentration of PCB contamination remaining on-site is anticipated to be minimal.[43, 44] Therefore, the use of poplars for phytoremediation is primarily intended as a recommended “polishing step” to further remove any remaining PCB material, to restore soil health and quality, and limit the spread of unwanted byproducts of the oxidation reaction.

LIMITATIONS

This thesis has several limitations. Direct access to the two sites of proposed remediation activity was limited by regulatory and physical barriers. Goodrich Pond has no direct access as it is surrounded by thick vegetation, private property, and a fence designed to restrict access to the pond from members of the public. Access to the Hill 78 and Building 71 OPCAs is heavily restricted; these sites are heavily guarded with high voltage fencing and continuously surveilled to protect against tampering. Non-authorized personnel are not capable of accessing the OPCAs and much of the former General Electric site. Consequently, analysis of the sites was limited to remote sensing methods, satellite imagery, and the review of existing documentation assessing contamination and conditions of the sites. Concerning remediation of the OPCAs, financial and technical limitations precluded the administration of an EPA method 8082 PCB mass spectrometry assessment to determine the current concentrations and depth of contamination within the landfills. Although somewhat specific data on contaminant concentrations in the OPCAs exists through EPA documentation, this data is not an adequate substitute for the method 8082 assessment. Over-the-counter PCB sampling kits are not an adequate substitute for this assessment, as they are not sufficiently sensitive, and contamination exists well below the subsurface. The recommended tests are not administrable without the engagement of a skilled technician and outside laboratory, permission to access the sites, and the use of specialized excavation and sampling equipment.

Another limitation arose from the historic data analyzing the long-term disposal of PCBs into the Housatonic River by General Electric. As mentioned, the figures provided in the 1970s and 1980s reports quantifying the mass of PCBs disposed in the river may be biased or inaccurate. This is because the studies were largely administered and funded by General Electric themselves, coupled with testimony from former plant employees tasked with the disposal and handling of transformer oils that suggest the quantity of dumped PCBs is higher than stated. Further, reports from the individual investigators and citizen scientists who first investigated the contamination in the 1970s suggest that some of their work may have been limited by General Electric.[19, 21, 34, 35, 79]

Lastly, providing accurate cost estimates for the two remediation strategies proved challenging due to multiple factors, including the novelty and specificity of the remediation methods, and a lack of data regarding the costs of comparable efforts. Consequently, this study does not present cost estimates and focuses solely on the methodology of the proposed remediation practices.

CONCLUSION

This work documented the status of PCB contamination in Pittsfield, Massachusetts, and presented innovative solutions to restore and remediate contaminated land, as opposed to the capping and storage of materials. The long-term environmental and public health impacts of PCBs warrant approaches to fully degrade and remove these chemicals from soils and groundwater, despite the challenging nature of remediation and cleanup. Even though PCBs were outlawed throughout much of the world in the late 1970s and early 1980s, contamination will persist for years to come without the use of aggressive remediation technologies. In Pittsfield, many contaminated sites have been successfully remediated, and contamination removed from the ecosystem. However, Goodrich Pond, the OPCAs, and the planned “Rest of River” remediation plan fall short of these high-level remediation measures and the protocols outlined in CERCLA.

Pittsfield, Massachusetts is merely one locality that has suffered the impacts of widespread PCB contamination, and many similar sites exist throughout the United States and the world. This work provided specific remediation plans for two sites in the Pittsfield; however, the recommendations of this report are applicable to the numerous similar capped landfills and contaminated waterbodies in the United States and abroad. This research aims to demonstrate that the removal and elimination of these so-called “forever chemicals” is feasible and urges the use of these methods to preserve the health and welfare of future generations.

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APPENDICES

Appendix A: Hydrologic Budget of Goodrich Pond

Area of Waterbody: 15.4 acres
Watershed Land Area: 63.0 acres
Total Area: 78.4 acres

Annual Precipitation: 48 in/yr

ET Rate: 50% or 24 in/yr
Evaporation Rate: 50% or 24 in/yr

Total Precipitation: (48in/yr) (1ft/12in) (43560ft/acre) (78.4 acres) = *13,660,416* ft^3*/yr*

Pond Evaporation: (24in/yr) (1ft/12in) (43560ft/acre) (15.4 acres) = *1,341,648* ft^3*/yr*

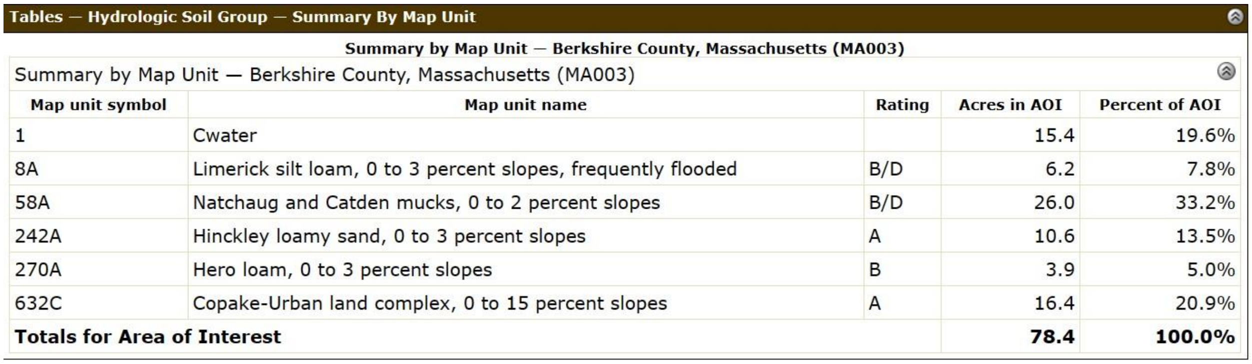
Watershed ET: (24in/yr) (1ft/12in) (43560ft/acre) (63.0 acres) = *5,488,560* ft^3*/yr*

Discharge: 13,660,416 ft^3/yr - 1,341,648 ft^3/yr – 5,488,560 ft^3/yr = *6,830,388* ft^3*/yr*

Direct P = EVAP = *1,341,648* ft^3*/yr*

SOIL CLASSIFICATION OF GOODRICH POND WATERSHED

Hydrologic Soil Group	Description	Recharge (in/yr)	Runoff (in/yr)
A	Sand & Gravel	23.5	0.5
B	Sandy Loam	17	7
C	Loamy Sand	13.5	10.5
D	Silt/Till	6.4	17.6



Tables — Hydrologic Soil Group — Summary By Map Unit

Summary by Map Unit — Berkshire County, Massachusetts (MA003)

Summary by Map Unit — Berkshire County, Massachusetts (MA003)

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
1	Cwater		15.4	19.6%
8A	Limerick silt loam, 0 to 3 percent slopes, frequently flooded	B/D	6.2	7.8%
58A	Natchaug and Catden mucks, 0 to 2 percent slopes	B/D	26.0	33.2%
242A	Hinckley loamy sand, 0 to 3 percent slopes	A	10.6	13.5%
270A	Hero loam, 0 to 3 percent slopes	B	3.9	5.0%
632C	Copake-Urban land complex, 0 to 15 percent slopes	A	16.4	20.9%
Totals for Area of Interest			**78.4**	**100.0%**

Note: Multiple-designated HSG will be considered D soils.

STUDY AREA INCL WATER = *342.5 acres*

Type A Soil: *34.4%; 27 acres*

Type B Soil: *5.0%; 3.9 acres*

Type C Soil: *0%; 0.0 acres*

Type D Soil: *41.0%%; 32.2 acres*

Water: *19.6%; 15.4 acres*

RECHARGE CALCULATIONS

Type A Soil: (23.5in/yr) (1ft/12in) (43560sqft/1acre) (27acres) = *2,303,235 ft^3/yr*

Type B Soil: (17.0in/yr) (1ft/12in) (43560sqft/1acre) (3.9acres) = *240,669 ft^3/yr*

Type C Soil: (13.5in/yr) (1ft/12in) (43560sqft/1acre) (0.0acres) = *0.0 ft^3/yr*

Type D Soil: (6.4in/yr) (1ft/12in) (43560sqft/1acre) (32.2acres) = *748,070.4 ft^3/yr*

Total Recharge: *3,291,974.4 ft^3/yr*

RUNOFF CALCULATIONS

Type A Soil: (0.5in/yr) (1ft/12in) (43560sqft/1acre) (27acres) = *49,005 ft^3/yr*

Type B Soil: (7in/yr) (1ft/12in) (43560sqft/1acre) (3.9acres) = *99,099 ft^3/yr*

Type C Soil: (10.5in/yr) (1ft/12in) (43560sqft/1acre) (0.0acres) = *0.0 ft^3/yr*

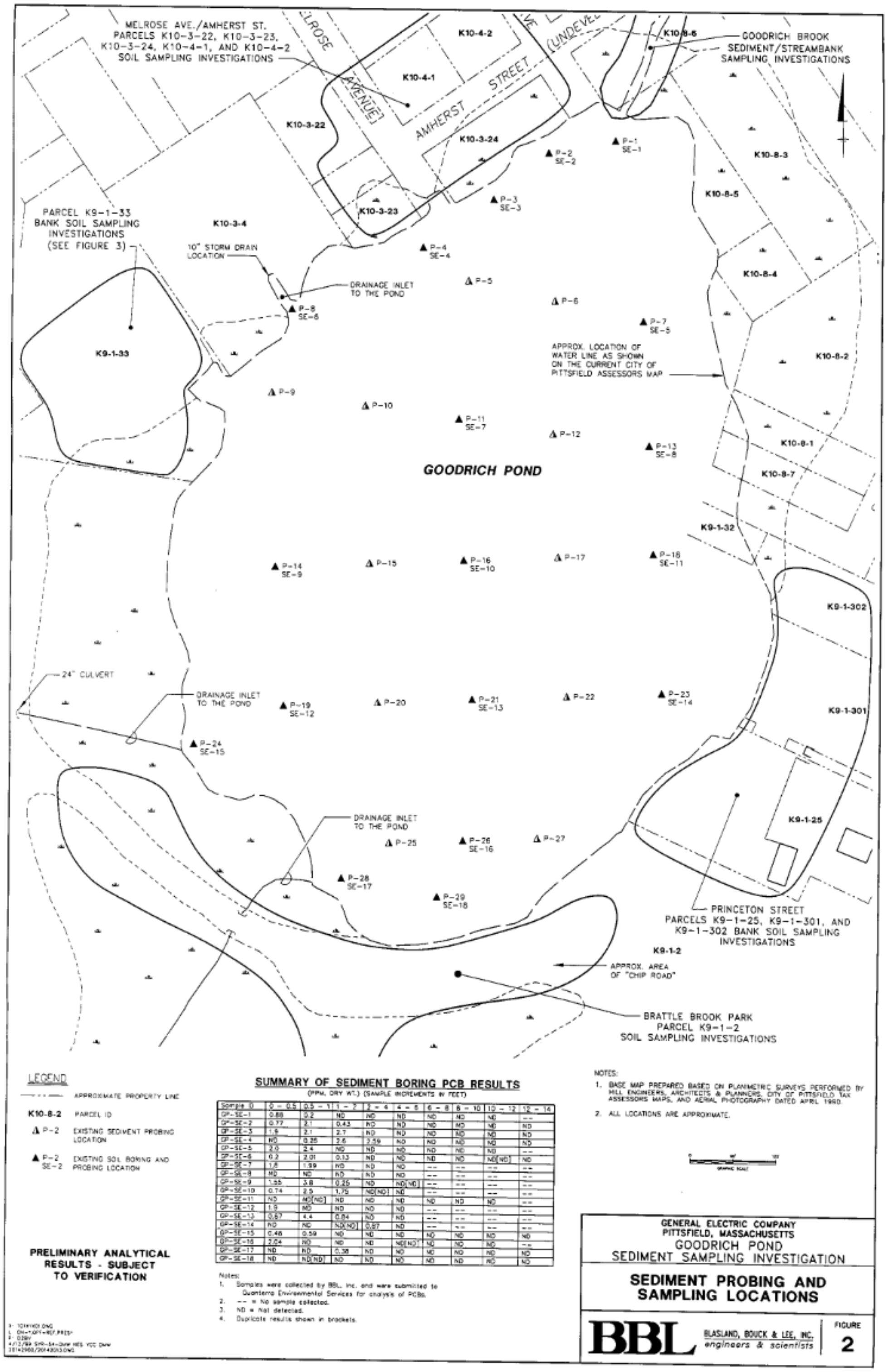
Type D Soil: (17.6in/yr) (1ft/12in) (43560sqft/1acre) (32.2acres) = *2,057,193.6 ft^3/yr*

Total Runoff: *2,205,297.6 ft^3/yr*

	Million CF/yr	AFY/yr
Total Precip.	13,660,416	313.6
Net Direct Precip. To Pond	1,341,648.0	30.8
Recharge	3,291,974.4	75.6
Runoff	2,205,297.6	50.6
Total Discharge	6,830,388	156.8

TOTAL: 156.8AFyr/365 = *0.43 AF/day*

Appendix B: Map of Soil and Sediment Sampling Conducted at Goodrich Pond



LEGEND

- APPROXIMATE PROPERTY LINE
- K10-8-2 PARCEL ID
- Δ P-2 EXISTING SEDIMENT PROBING LOCATION
- ▲ P-2 SE-2 EXISTING SOIL BORING AND PROBING LOCATION

PRELIMINARY ANALYTICAL RESULTS - SUBJECT TO VERIFICATION

SUMMARY OF SEDIMENT BORING PCB RESULTS

(PPM, DRY WT.) (SAMPLE INCREMENTS IN FEET)

Sample ID	0 - 0.5	0.5 - 1	1 - 2	2 - 4	4 - 6	6 - 8	8 - 10	10 - 12	12 - 14
GP-SE-1	0.88	0.2	ND	ND	ND	ND	ND	ND	--
GP-SE-2	0.77	2.1	0.43	ND	ND	ND	ND	ND	ND
GP-SE-3	1.9	2.1	2.7	ND	ND	ND	ND	ND	ND
GP-SE-4	ND	0.25	2.6	2.59	ND	ND	ND	ND	ND
GP-SE-5	2.0	2.4	ND	ND	ND	ND	ND	ND	--
GP-SE-6	0.2	2.01	0.13	ND	ND	ND	ND	ND[ND]	ND
GP-SE-7	1.8	1.99	ND	ND	ND	--	--	--	--
GP-SE-8	ND	ND	ND	ND	ND	--	--	--	--
GP-SE-9	1.65	3.8	0.25	ND	ND[ND]	--	--	--	--
GP-SE-10	0.74	2.5	1.75	ND[ND]	ND	--	--	--	--
GP-SE-11	ND	ND[ND]	ND	ND	ND	ND	ND	ND	--
GP-SE-12	1.9	ND	ND	ND	ND	--	--	--	--
GP-SE-13	0.67	4.4	0.84	ND	ND	--	--	--	--
GP-SE-14	ND	ND	ND[ND]	0.87	ND	--	--	--	--
GP-SE-15	0.48	0.59	ND	ND	ND	ND	ND	ND	ND
GP-SE-16	2.04	ND	ND	ND	ND[ND]	ND	ND	ND	--
GP-SE-17	ND	ND	0.38	ND	ND	ND	ND	ND	ND
GP-SE-18	ND	ND[ND]	ND	ND	ND	ND	ND	ND	ND

Notes:
1. Samples were collected by BBL, Inc. and were submitted to Quanterra Environmental Services for analysis of PCBs.
2. -- = No sample collected.
3. ND = Not detected.
4. Duplicate results shown in brackets.

NOTES:
1. BASE MAP PREPARED BASED ON PLANIMETRIC SURVEYS PERFORMED BY HILL ENGINEERS, ARCHITECTS & PLANNERS, CITY OF PITTSFIELD TAX ASSESSORS MAPS, AND AERIAL PHOTOGRAPHY DATED APRIL 1990.
2. ALL LOCATIONS ARE APPROXIMATE.

GENERAL ELECTRIC COMPANY
PITTSFIELD, MASSACHUSETTS
GOODRICH POND
SEDIMENT SAMPLING INVESTIGATION

SEDIMENT PROBING AND SAMPLING LOCATIONS

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 2

X: 10Y41X01.DWG
L: ON=*,OFF=REF,PRES*
P: 02BV
4/12/99 SYR-54-DMW HES YCC DMW
38142960/20142X03.DWG

Appendix C: Groundwater Monitoring Locations at the OPCAs, 2018