Spring 5-2009

Designing the Phytoremediation Landscape: Exploring phytoremediation of urban brownfields as a system and stage in designed and managed successional processes

David N. Maynes
University of Massachusetts - Amherst, dmaynes.designer@gmail.com

Designing the phytoremediation landscape:

Exploring phytoremediation of urban brownfields as a system and stage in designed and managed successional processes.

by

David N. Maynes

A PROJECT SUBMITTED FOR THE PARTIAL FULFILMENT OF REQUIREMENTS FOR MASTER OF LANDSCAPE ARCHITECTURE DEGREE

MAY 2009

Department of Landscape Architecture and Regional Planning
University of Massachusetts, Amherst

Approved as to style and content by:

____

Committee Chair
Assistant Professor Frank Sleegers
Landscape Architecture and Regional Planning

____

Committee Member
Professor Guy R. Lanza, Ph.D. Professor of Microbiology
Director, Environmental Science Program

____

Committee Member
Professor Mark Lindhult, FASLA
Landscape Architecture and Regional Planning

____

Elizabeth Brabec, Department Head
Landscape Architecture and Regional Planning

Table of Contents

Acknowledgments

I extend my thanks to Prof. Frank Sleegers for inspiring me to explore the world of contaminated places and their recovery using both the beauty of design and logic of science.

I thank Prof. Mark Lindhult for his wonderful ability to maintain my focus and direction during the process of creating this document.

I thank Prof. Guy Lanza for his enthusiasm for this project and for sharing his passionate knowledge of the microscopic world with me.

I extend warm and unprecedented thanks to my wife Kell, whose support was undying and unconditional throughout my graduate studies. Completion is as much her reward as it is mine.

And finally, to my son Ambrose for forcing me to take occasional breaks to explore his world and inspire mine.

Project Summary

The present day challenges facing the post-industrial city are economic reinvention, social equity, and environmental recovery. The urban mosaic of these places is vague and broken, and demands new and innovative solutions for the reclamation of vacant, abandoned, and contaminated landscapes that create a unification of economic, environmental, and cultural healing. A multi-scalar approach is proposed as a strategy for the integration of multiple components in multiple contexts. Particular focus is on the synthesis of community engagement and environmental remediation of these spoiled, derelict lands. Specifically, phytoremediation is explored as a solution for land reclamation, ecological and social recovery of parcel-scale urban open spaces. Discussion of how design intervention at multiple scales can be synthesized, the temporal dynamic of remediation, and the potential for integrating ecological natural attenuation and land-use activation simultaneously as a component of a staged and managed urban land succession, are explored. The problems and opportunities associated with the resurrection of the post-industrial city are vast and multifaceted. This project will propose strategies through design that attempt to merge the elements of sustainability into a new and replicable cultural, environmental and urban cleansing initiative.

Introduction

The Post-Industrial City

Cities of industry have long been the backbone of American growth and prosperity. The production of goods for an increasing population spawned the industrial development of the early 20th-century and catalyzed urban economic and cultural growth. Neighborhoods emerged, traditions from immigrant families began weaving a rich social fabric, and places arose out of a landscape of spaces. Corner stores became the social anchors of neighborhoods; apartment stoops the linkages. The urban network was strong and diverse; genuine and optimistic. The unconscious connection of the human spirit through a symbiotic reliance and known pride defined and illuminated the cross-cultural urbanism of the time, and the resulting spatial habits created a sense of place. The allure of such a place, the generational steadfastness, and the social and economic security that maintained the future of the industrialized city did have its consequences.

With intensive resource harvest and ballistic production scales, a multi-generational environmental tragedy was unraveling. The utopian city of opportunity and cultural goulash was becoming a sink of pollution and storehouse of contamination. It wasn't until the environmental awakening of the early 1960's with the publication of literary works by individuals such as Aldo Leopold and Rachel Carson, and environmental catastrophes such as the burning Cuyahoga River in Ohio that illuminated the extent to which the industrialized city had impacted the environment and its occupants. This dismal awakening catalyzed environmental oversight and regulation that began in part, the steady decline of the industrialized city. The Clean Water Act, Clean Air Act, and formation of the Environmental Protection Agency and state departments of environmental protection set into motion a shift in urban priority. Production was no longer the sole focus. Instead, it merged with the need for improving the mechanisms by which production was carried out. No longer was the acceptable routine of hazardous wastes being cheaply discarded onsite or in adjacent waterways' an option for industrial operators.

It was with this advent of environmental politics, and subsequent legislative and regulatory additions in years following such as CERCLA, that the industrialized city began to deteriorate. It is not to say that the death of America's industrialized cities was entirely due to the new, expensive and threatening regulatory framework set in place, but rather an accelerant of economic stress, consequential social impacts, and existing partially understood environmental decline. As urban populations began to decrease due to private-owner fear of environmental liability and globalization (this to a great extent due to the ability of an industry to avoid regulatory oversight in less developed countries) the final days of the industrialized city began to play out. Regional industries of mixed scales were crumbled by giant industrial corporations because of their inability and/or unwillingness to migrate to more conducive production environments (i.e. China). Today, the quintessential post-industrial city is easy to find. Urban blight, social inequity, remaining environmental distress, poverty, crime, and deteriorating infrastructure are all rampant in the post-industrialized city, and greatly contribute to economic and cultural stasis. The perception of place is of immense importance, and is likely the most detrimental element in recovering and reinventing the post-industrial urban environment. Brownfield perception and reality is what manifests potential and proven environmental liability. Liability is the devil of new industry. The post-industrial American city is at a complicated crossroads. It is ripe with potential, but bruised by real and perceived issues. It is with the present-day green revolution that the greatest possibilities lie for the resurrection and recovery of these once rich urban places.

Project Discussion

Location and Context

The study area is focused in the City of Holyoke, MA. Located in western Massachusetts along the Connecticut River, Holyoke was conceived as a planned industrial center for the region. Known as the 'Paper City', the industrial production of paper, and related products became the identity of the city, and attracted large Irish and Italian immigrant populations in search of employment. Unique to Holyoke within the New England context was the conscious spatial planning and design of the city in order to maximize industrial optimization. Unlike most New England industrial cities that grew more organically over time; the establishment of a multi-level canal system, gridded street network, and integrated abundance of rail lines made Holyoke a production-based landscape from conception. The canals are a dominant feature in the landscape. Designed primarily for hydro-electric power to fuel the industrial engine, the canals funnel water from the northern tip of the industrial core via the Connecticut River. There are three canals total with surface and subsurface connecting spill water raceways. Each canal steps down in elevation from the other in order to exploit the gravitational power of water. Large industrial brick buildings hug the canals and epitomize the industrial architecture of the time with powerful structure and facades evocative of economic prosperity and industrial pride. In its hay-day, Holyoke defined industrial beauty and optimization. In present day the untouched relics of the past still maintain a quiet grandeur that seemingly whisper a longing for new purpose and identity. The canals, physically unchanged, flow without the turbulent spirit that once formed the urban-industrial cultural milieu. Although still producing energy, the canals have lost the daily personal engagement that once existed. The abandonment of industry continued for most of the late half of the 20th-century resulting in job loss, and subsequent urban decay.

Today, numerous regional, state, and city efforts are being made to revitalize Holyoke's industry, heritage, and reputation. In 2007, a joint study done by the Brookings Institute and the Massachusetts Institute for a New Commonwealth entitled ***Reconnecting Massachusetts Gateway Cities:*** *Lessons Learned and an Agenda for Renewal,* compiled a list of eleven former industrial cities that today demand greater attention and revitalization efforts. The 'Gateway Cities' were determined based on sharing a legacy of economic success through manufacturing during the early part of the 21st-century, and subsequent decline resulting from the state's economic shift towards skills-centered knowledge sectors, which cluster in and around Boston. Additionally, communities adopted as Gateway Cities had a population greater than 35,000 and high incidence of poverty. Key findings of the research found that between 1970 and 2005, Boston added close to 500,000 jobs, while as a group the Gateway Cities lost more than 11,000 jobs. It was also found that the combined manufacturing job loss in Gateway Cities since 1960 totaled 134,000 accounting for more than one-third of the State's total decline in manufacturing industries. In summary, the document proposed revitalization solutions using knowledge-based industry development as a mechanism for increased job opportunities. Inherent to the recommended reinvention of industry is the need to explore new technologies (green), the rehabilitation of aging infrastructure, and reclamation and decontamination of currently unavailable urban lands.

While the solutions proposed in the study focus on economic recovery as a means of satisfying both State and municipal goals (i.e. affordable housing, increased workforce, etc.), the need for a holistic and unified recovery strategy is urgent. The synthesis of State priorities, city vision, and community engagement would allow for a symbiosis of reinvention and revitalization initiatives. In Holyoke, progress is slow but steady. Efforts to establish affordable housing have been successful, yet employment opportunities still remain elusive. Contaminated, unusable land still sits idle in need of redevelopment. To confront the extensive brownfield problem, the city applied for and was awarded an EPA Pilot Assessment Program grant which financially aids in inventorying and assessing suspected brownfields in the city. To date, numerous sites have been determined contaminated and in need of remediation prior to redevelopment. While identification is a first step, implementation of a solution is a much more complicated and traditionally expensive matter. Discussion of urban brownfields and the complexities of redevelopment will be highlighted in the literature review of this document. In summary, brownfields in Holyoke are in need of cheap, effective and integrated solutions for redevelopment. Municipal and community vision for renewal of these landscapes can be interwoven into the reclamation processes allowing for monetary resources to be multi-functional. A grant for remediation expenses can as well function to simultaneously support redevelopment initiatives. Though currently not the norm and requiring greater investigation and diligence, unification of multiple components of renewal can be fused into a system of economic, social, environmental, and cultural urban healing.

Concept

This project explores the use of phytoremediation as a strategy for recovering contaminated urban land, phytoremediation as an individual and collective experience on a site scale, phytoremediation as a catalyst-stage for designing, planning, and managing urban land succession in multiple spatial and temporal scales, and the synthesis of each in a unified urban initiative for parcel reclamation in the City of Holyoke, MA. Opportunities and limitations of phytoremediation in these contexts are discussed. Site scale design of a known and assessed brownfield offers a model for integrating phytoremediation with land-use activation and redevelopment. Recommendations for dynamic land-use programming in concert with remediation strategies are proposed. Particular scientific investigation is on contaminant-site specificity and multi-process phytoremediation systems involving the simultaneous and/or phased use of multiple remediation techniques including: land-farming, microbial inoculation, phytoremediation with the use of plant-growth-promoting amendments. Design engagement with applied science is thoroughly explored.

Goals and Objectives: general

The goal of the project is to grow an understanding of urban land reclamation in multiple scales using innovative remediation strategies synthesized with artful design. Specific concerns regarding the use of phytoremediation in this context is foremost and thoroughly researched in hopes of gaining practical and applicable knowledge that may be used in future design endeavors and community healing initiatives. The objective of the project is to establish a model that could be replicable in other post-industrial cities. It is also the intent to provide the City of Holyoke a cost-effective remediation alternative for priority redevelopment of brownfield sites located in the city.

Goals and Objectives: 191 Appleton Street - former Adams Pakkawood

The goal for the design of the site involves the simultaneous remediation and activation of the landscape as an urban park. It is also the intent to understand the relationship between specific contaminants, site characteristics, and applied phyto-technology as inspiration for the spatial organization, social expression, and qualitative value of the contemporary urban open space experience. Integration and connection of the site will be made as a spatial and cultural anchor with current adjacent open space improvements and redevelopment efforts being implemented by the city.

The objective of the site design is to incorporate peer-reviewed scientific research of specific contaminants, efficacious methodologies, and biological and metaphoric succession models as a way of exploring performance design beyond what currently exists as precedent in the profession of landscape architecture. It is my intent to go beyond the typical design proposal of a mere nod to phytoremediation as a land reclamation strategy, and consider the chemistry, designed implementation and monitoring, and agronomic science of successful land cleansing in concert with spatial expression in hopes of illuminating potential new design typologies and development of strategies for the creation of active and dynamic land use while in remediation.

Methodology

The methods for developing concepts to fuse ecological remediation science with spatial design as a redevelopment model for a known brownfield in Holyoke include:

interviews with city planning officials to better understand the municipal vision for the site, interviews with non-government organizations such as Nuestras Raices to become familiar with the vision of a community as represented by the urban agricultural non-profit in hopes of inspiring production-based land reclamation solutions, and extensive scientific research into ecological remediation methods including phytoremediation, bioremediation, and agronomic techniques supportive of successful site decontamination. Additionally, exploration of ecosystem succession including theories, proposed hierarchies, and implications for integration with ecological remediation design will be conducted.

The fusion of landscape architecture with remediation design will be thoroughly explored.

Analysis and Assessment

Regional

Holyoke lies in the Pioneer Valley which includes three counties; Franklin, Hampshire, and Hampden, and is comprised of 43 individual municipalities located within the Massachusetts section of the Connecticut River Valley. A diverse mix of urban and rural landscapes comprises the region. Ethnicity ranges from European descent dominating the more rural counties of Franklin and Hampshire counties to non-European populations, mainly Latino dominating the more urbanized and industrial Hampden County. Total population of the Pioneer Valley is a little above 700,000 people. Populations of individual counties range from: Franklin, 71,000; Hampshire, 153,000; and Hampden, near 500,000. (PVPC, 2007)

A diverse landscape makes up the Pioneer Valley. The Connecticut River is the dominant water body which stretches from northern Vermont extending into Long Island sound. Flanked in the west by the foothills of the Berkshire mountains, the river's alluvial floodplain boasts some of the most productive agricultural soils in the both the State and New England. Primary industries in the Pioneer Valley consist of agriculture and education in Franklin and Hampshire counties, and manufacturing in Hampden County.

Median household income in Hampden County is ~$39,000/yr, much less than both Franklin and Hampshire counties, with poverty levels at around 12%, approximately 7% higher than other counties in the region. (PVPC, 2007)

The heavily urbanized Hampden county consists of four large metropolitan municipalities including Springfield, Holyoke, Westfield, and Chicopee. The cities of Holyoke and Springfield both suffer from intense symptoms of a post-industrial economy; urban blight, poverty, high crime rates, and lack of job opportunities. Reinvention and renewal of strong industries in both municipalities is needed to create greater opportunity and prosperity not only in the municipalities themselves, but the greater Pioneer Valley region.

City of Holyoke

While currently struggling to revitalize and reinvent industry, Holyoke still remains a dominant industrial center in the Greater Springfield urban area.

Demographics

Total population of the city is approximately 39,000 (as of 2006), with a dominant racial profile of 55% white, and 45% Latino. The dominant population age range is between 25 and 50 years old (~38%). Employment is primarily service oriented (56%), with manufacturing the second largest employer at a mere 11%. The average annual wage is ~ $34,000, and household median income is ~ $37,000. Approximately 55% of residents commute out of Holyoke for employment with the remaining 44% working within the city. Household income ranges are shocking in that while 20% of households bring in $75,000 or more per year, near 18% of households bring in less than $10,000 per year and the percentage of persons living below poverty level is 26% (as of 2000). The city has a range of housing, from urban apartment complexes within the former industrial neighborhoods of 'South Holyoke' and 'The Flats', to single family homes in the upland areas.

Spatial Data

Total land acreage in the city is approximately 14,000 acres or 22 square miles that consists of both the heavily urbanized industrial landscape adjacent to the Connecticut River, and more rural hilly uplands including Mt. Tom just west.

Land Use

Land use is dominated by residential and undeveloped (mostly outside the industrial core) uses, and waterways (the canals). Industrial, commercial and civic open spaces are all equally dispersed, while agricultural, recreational and transit-based (roads and rails) land uses are the least abundant.

Zoning

Zoning in the city is dominated by both residential and industrial, with small pockets of commercially zoned land in the central business district and adjacent to industrial/residential neighborhoods. The city is in great need of zoning reform to enable healthier residential environments and integration of commercially zoned sections with industrial lands. The current lack of updated zoning creates serious environmental justice issues in the neighborhood of South Holyoke where heavily contaminated industrial sites abut multifamily residential areas. Historically, providing workforce housing in and around manufacturing facilities allowed for walkable commuting, but with the present day absence of continued manufacturing at the former industrial sites, residential proximity only promotes negative human health impacts, racial isolation, and lack of employment opportunity within the industrial core of the city.

Circulation

The circulation in Holyoke is extremely efficient due to the gridded network of roads established during the city's physical birth and construction. Though networked for optimization, circulation is dominated by vehicular traffic on few primary roads and generally lacks safe pedestrian ways within the industrial core. Sidewalks do exist, but the majority are narrow, threatening, and in disrepair. Few public transit stops exist and are typically isolated within the central downtown area. Rail lines are extensive as a result of former industrial necessity. Most local lines are now not in operation, but serious discussion between the city and rail owners is currently underway to provide commuter rail service in and out of the city, enabling a much needed regional and state public transit connection.

Impervious Surface

Impervious surfaces dominate the industrial core of the city. Pockets of wild vegetation in and adjacent to the canals, former overgrown manufacturing sites, and few parks offer spaces of stormwater infiltration. There is a great need for enhanced infiltration sites in order to decrease contaminated runoff into the abundant (and protected) waterways that dominate the city landscape and eventually flow into the Connecticut River.

Open Space

Open spaces are many in the city, but are completely fragmented and disconnected. As mentioned, inadequate pedestrian infrastructure and inhospitable streetscapes are the major cause for open space fragmentation. Many parks struggle to be maintained, and few offer reasonable amenities and functionality to be purposely visited. Heritage State Park is the dominant urban open space and provides visitors with amenities such as a vintage merry-go-round which is the only operational one of its kind, a praised children's museum, open turf areas with facilities, and the Volleyball Hall of Fame. The park lies directly adjacent to retail and commercial amenities downtown, along the 1st-level canal, and within the new Arts and Industry District. It also will be connected to the newly constructed Canal Walk located east across the canal. Few, if any open spaces provide connection with the Connecticut River. The lack of active and passive recreational areas along the river greatly impedes any future connection of the downtown, canal walk, and Arts and Industry District with the river. Efforts must be made to aid in connection of these vital areas in order to not only provide local amenity and connection, but as well a regional connection via the Connecticut River Greenway.

Brownfields

There are 16 known and assessed brownfields located in the urban core of Holyoke. The majority of sites lie in the industrial areas east of the 1st-level canal and are a result of manufacturing production. Most sites have Activity and Use Limitations (AUL) and cannot be redeveloped until remedial action has been taken and a Response Action Outcome (RAO) Statement has been authorized by the Massachusetts Department of Environmental Protection. In order to facilitate resource allocation for informed redevelopment, the city together with the Pioneer Valley Planning Commission developed a Brownfield Inventory and Redevelopment Priority matrix. The matrix highlights the parcels that pose either a significant safety hazard and/or offer high potential for economic, social, cultural, and environmental return. Those that offer a combination of positive returns were determined high priority. While effective in organizing a critical path for reclamation, the matrix neglects fundamental urban design principals and disregards the need for holistic urban renewal. In addition, reclamation resources considered only traditional remediation strategies with little thought of how monetary expenses could be more effectively managed for multiple parcel reclamation using ecological remediation strategies. The brownfields in Holyoke offer great opportunity for experimental design, new catalysts for urban networking, and industrial reinvention opportunities within the city. To nest them within a priority framework, though organizational, defines them as nuisance sites rather than genesis sites for progressive planning and design to born out of.

191 Appleton Street - former Adams Pakkawood

The former Adams Pakkawood site is located on Appleton Street situated between the Holyoke canal system's first and second level canals to the northeast and southwest, respectively. It is adjacent to the center of downtown, Heritage State Park, and proposed canal walk (to begin construction in March of 2009). The currently vacant city-owned parcel is one acre and primarily covered with grass vegetation. A spill water raceway sits directly north of the parcel line and has great potential for incorporation into the final site design. The site is currently zoned as 'general industry' and is surrounded to the east, north, and south by active and inactive industrial land-use. This high visibility location provides the greatest potential for parcel-scale site design of urban open space as experiential phytoremediation.

Surrounding Resource Areas

The site lies above a medium yield aquifer that is classified as a Non Potential Drinking Water Source Area. No areas of Environmental Critical Concern or Sole Source Aquifers are located within 500 feet of the site. The site does lie within 500 feet of a NHESP Priority Habitat of Rare Species and Estimated Habitat of Rare Wildlife associated with the adjacent canals.

Site Use History

Historical records indicate the site was first developed in 1884 as a textile mill. In 1889 the addition of a four-story building and support buildings in and around the existing mill race with connections to industrial space located on the adjacent 195 Appleton (due north). The American Thread Company occupied the building until approximately 1952, at which point the Adams Plastic Co., later renamed Adams Pakkawood, operated until 1991. The building sat vacant from 1991 until 1993 when it burned and soon thereafter demolished by the city. Records indicate that the oil and hazardous materials used and/or generated by operations at the former facility include phenolic resins, hydraulic oils, tumbling lacquers, lacquer thinners, polypropylene, n-propyl acetate, cutting oils, printing inks, cadmium sludge, solvents and degreasers.

Environmental Conditions on Site

Laboratory results performed by Tighe and Bond indicated that carbon fractions were detected above the Massachusetts Contingency Plan Reportable Concentrations and Method 1 Cleanup Standards in subsurface soil samples collected from borings on the northern point of the site, within the foundation footprint of the former site building. Several target Poly-Aromatic Hydrocarbons (PAHs) and Semi-Volatile Organic Compounds (SVOCs) were detected above applicable standards in the soil. The contaminants were primarily confined to fill soils approximately five to ten feet below grade from where soil borings were advanced. The release of these contaminants is suspected to be a result of the 1993 fire disturbance and subsequent demolition activities. The total volume of impacted soils is estimated to be between 500 and 850 cubic yards. No groundwater contamination was detected. While contaminant levels detected were greatest between the depths of five and ten feet, supporting documents indicate likely levels of concern between one and four feet below existing grade. Low levels of Nickel (Ni) were also detected between one and two feet below grade in an isolated spot on the southern side of the site approximately 15' off the existing sidewalk. Site remedial action recommended by Tighe and Bond was excavation, removal, and relocation of contaminated soil to a proper landfill facility out of state. The estimated costs for remediation started at ~ $120,000. The approximation is based on the potential for discovery of more contaminants, and general estimates for project completion. (Tighe & Bond, 2004)

Literature Review

Introduction

The literature reviewed for exploring the integration of design with phytoremediation is diverse and multi-disciplinary. This study highlights the dominant and obligatory components of brownfield reclamation through the lens of urban and site design with particular focus on the science, application, and expression of phytoremediation. The review consists of an overview of **urban brownfields** and the social, environmental, and economic challenges for redevelopment they pose to the private owner or municipality. Attention is given to the community impacts of spatial proximity as a result of municipal planning. A brief summary of the current Federal and State regulatory framework illuminate the challenges associated with brownfield remediation in the urban environment. Discussion of current assessment procedures and their accompanying methodologies will follow, further highlighting the fiscal challenges of contaminated land redevelopment for both municipal and private entities.

Phytoremediation is discussed in detail. A general overview of the fundamental components of phytoremediation is highlighted and elaborated on. Limitations and opportunities of application in the urban environment are discussed. Discussion of phytoremediation mechanisms will be fused with specific organic and inorganic contaminants, namely poly-aromatic hydrocarbons (PAH's) and lead (Pb) respectively, pertinent to this study and design exploration. Phytoremediation as a nested component within a **Multi-Process Phytoremediation System** (MPPS) is thoroughly discussed and implications on spatial design and planning using a Multi-Process Phytoremediation System are explored. Focus and insightful commentary is on phytoremediation as an expressive and spatially and temporally experiential element as a stage in designed and managed urban land succession.

Urban Brownfields

Introduction

The decline of industrial production in the urban environment has left the post-industrial city with a patchwork of contaminated, vacant, and abandoned landscapes that greatly affect the communities in which they lie. Redevelopment of these sites is often complicated and wrought with potential liability and uncertainty.

The official EPA definition of a brownfield is:

Real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant'. (USEPA)

Brownfields in the urban environment are a much greater and immediate threat to human health and the environment than those located in less populated areas. In addition to the inherent toxicity and associated biological impacts, urban brownfields dramatically affect the socio-economics of neighborhoods, the community, and the greater metro-region. Typically, multi-family housing once sited for worker convenience and walkable commutes, remains unchanged even in the absence of active industry. This creates municipal complacency. Zoning laws that once supported active and proud multi-cultural middle class workforce neighborhoods remain unchanged and now foster social and cultural isolation within the urban system. This isolation is often due to the need and/or mandate for affordable housing within and adjacent to the urban core. The combination of unrevised zoning, sub-standard and aged housing stock, lack of job opportunities, and proximity to contaminated parcels often times reads as a recipe for emergent urban blight and municipal disassociation (although most municipal planning agencies would argue differently). This disassociation is clearly evident in the unwillingness and/or lack of progressive planning strategies to accommodate, catalyze, and implement effective and just revitalization efforts. Municipal planning agencies, though a contributor, are not the greatest obstacle for reclaiming and reinventing these landscapes. It is no surprise that the landscape itself prevents renewal and positive socio-economic growth. The liability of brownfield ownership is immense and is by far the greatest setback to parcel reclamation and redevelopment.

Regulatory Environment

In 1980 congress passed the Comprehensive Environmental Response, Compensation, and Liability Act, or CERCLA and is most commonly referred to as Superfund. This legislation dramatically changed the way potential and existing pollution is dealt with in the legal environment. Essentially the law states that sites containing known hazardous waste(s) are subject to prohibition and parties who engaged in the creation of contamination are liable for the cleanup. Liability also includes parties who hold entitlement to a parcel even if said parties' actions did not directly cause the pollution, such as a landowner or developer who purchased a parcel without knowledge of existing, sometimes unknown contamination. The law also created a trust fund from new taxes placed on polluting industries, to provide resources for cleaning contaminated sites where no responsible party can be identified. CERCLA was amended in 1986 as the Superfunds Amendment and Reauthorization Act, or SARA and was designed based on the six years of knowledge gained from the incorporation of CERCLA. Several amendments were made and include the following:

- ***stressed the importance of permanent remedies and innovative treatment technologies in cleaning up hazardous waste sites;***
- ***required Superfund actions to consider the standards and requirements found in other State and Federal environmental laws and regulations;***
- ***provided new enforcement authorities and settlement tools;***
- ***increased State involvement in every phase of the Superfund program;***
- ***increased the focus on human health problems posed by hazardous waste sites;***
- ***encouraged greater citizen participation in making decisions on how sites should be cleaned up; and***
- ***increased the size of the trust fund to $8.5 billion*** (USEPA)

The amendments made in SARA made an attempt at partially streamlining the redevelopment of brownfield sites. CERCLA, with all its good intent, directly influenced the pace at which site reclamation and redevelopment took place. It in fact, slowed the reclamation of contaminated sites to a near halt due to responsible parties leaving abandoned industrial land in fear of fiscal costs associated with obligatory remediation. It is much cheaper to let land sit vacant and idle then to decontaminate it for future marketability. The establishment of SARA was forward-minded, but still maintained the CERCLA consequences for liable parties. In what was seemingly a strategy for optimization, SARA encouraged greater State involvement in the recovery of hazardous waste sites. This in reality created a multi-source liability. State programs created to foster brownfield cleaning and redevelopment, were often times disconnected from the federal framework and therefore created additional complexity and uncertainty in site remediation compliance. This regulatory segregation between State and Federal cleanup standards/agreements deeply affected the legal landscape in that the liable party, whether potential purchaser or existing owner, needed to conform to two, often discontinuitous standards of parcel recovery. As a method to alleviate this, the EPA stated a commitment to State regulatory oversight to use risk-based clean-up parameters rather than the EPA's traditional standards of clean-up being defined based on the risk to humans remaining constant. This traditional standard assumed future land-use to always be 'residential' (scientifically defined as a 6-year old child ingesting 200mg of contaminated soil every day for 5 years), thus requiring the greatest level of decontamination, in turn dramatically impacting and elevating remediation costs even if future land use was to maintain as industrial. In 1995, the EPA restated its commitment to the idea that actual future land use should be taken into account when choosing a remedy, but despite this, the State-Federal regulatory disconnection remains. To further overcome purchaser fears of dual accountability, and encourage greater coordination between both State and Federal agencies the EPA developed guidelines for agreements known as 'Memoranda of Agreement'. Completed in 1996, the 'MOA' guidelines are used to align State and Federal statutory enforcement efforts and work in concert with state voluntary cleanup programs on specific projects. It states in summary:

'The EPA will not exercise cost recovery authority and does not generally anticipate taking CERCLA removal or remedial action at sites covered by a MOA except under limited circumstances detailed in the guidance'

(Kirkwood, 2000)

Additionally, MOA's allow parties to work together to support protective cleanups and sustainable redevelopment. Brownfield redevelopment can only be sustainable when it is a transparent process protective of public health (O'Reilly & Brink, 2006). In 2001, realizing that inner city residents had to engage in the process of urban land reclamation, the EPA developed the Small Business Liability Relief and Brownfield Revitalization Act, allowing the EPA to award $250 million a year in grants to local governments for assessing and cleaning up contaminated sites. In just a few months following the EPA announcement, it had awarded $73.1 million to 176 applicants.

The complexity of both the State and Federal regulatory environments individually and combined, is staggering. It is only in recent years that attempts and successes have been made to truly align and engage policies for the remediation of contaminated sites. The discussion of urban brownfields in this review is extremely basic and meant to convey a sense of the complicated and often hugely multi-faceted nature of reclaiming these idle urban lands. To understand the multitude of various programs and initiatives created by both the EPA and State agencies, and how they can be synthesized for individual site reclamation, one must tailor and assimilate a political, cultural, economic, and regulatory cocktail for a specific site. There is no 'one size fits all' arrangement available; only customizable tools.

Assessment and Redevelopment

In the United States, there are approximately 600,000 brownfield sites and an estimated 5 million acres of abandoned industrial properties. Most, if not all, are concentrated in urban areas and range from former industrial properties to debunked gas stations (Environmental Law Institute). In New York City alone there is approximately 4000 acres of brownfield sites, 3000 of which are located on high valued waterfront property (Mueller, 2005). To understand the spatial scale, one can compare it to Central Park which is approximately 900 acres. Most of the 600,000 sites are corporate owned and typically held at a depreciated book value which is most often far less than the costs associated with cleanup. As a result, new development is isolated to greenfields in the urban hinterlands (suburbs), further compounding the problem. It is estimated that approximately 4.5 acres of greenfield sites are saved for every one acre of brownfields redeveloped (USEPA, 2001). This number, when considering the total acreage of brownfields existing, explicitly confirms the necessity for recovering these derelict sites and curbing future development of ecologically valuable and multi-productive landscapes. The current need for property cleanup and reuse is so great that in many cases the cities/municipalities in which contaminated parcels reside are willing to condemn the sites, take ownership, and assume the regulatory responsibility of cleanup to move revitalization projects forward. The EPA Brownfields Redevelopment Program of 1995 (primarily an economic development tool with an inherent environmental component) cited two immense hurdles to redevelopment of contaminated land: making redevelopment profitable following the excessive and often unpredictable expense of remediation, and protecting human health. Based on this, much effort has been made in recent years to develop assessment models of various types to aid in both health-related analysis and economic development potential. A New York county citizen's advisory group developed a risk-matrix to evaluate the uncertainty of available site data, the toxicity of known or suspected contamination, and the likely exposure rates and pathways. The matrix categorizes brownfield sites as high, medium, and low risk exposure groups (O'Reilly & Brink, 2006). Development of a risk exposure matrix is useful in that it enables informed remediation goals. While this helps determine the monetary liability of redevelopment and lessens developer angst regarding acquisition of brownfield parcels for future development, it promotes and maintains a linear and traditional approach to urban land reclamation.

Enabling a dispersed liability amongst multiple invested parties outside of a heavily regulated environment offers a much more appealing solution. Brownfields Capital is a financing company that specializes in brownfield redevelopment. BC's investment process provides sellers with a method to address their legal liabilities for site cleanup using outside capital that does not affect their core business. It provides necessary capital to enable these transactions to take place. If widely accepted, it could create an active market for brownfields that currently does not exist. The intricacies of the model are complex, but essentially the company uses bond-like instruments called Brownfield Value Contracts (BVC) that are a way to capitalize on disequilibrium in the capital markets created by environmental law rather than a temporary undersupply or oversupply in real estate markets. BC acts as a specialty financial intermediary that provides financing for the remediation and redevelopment of brownfields using a unique system for reducing and managing risks associated with contaminated sites. The system consists of an underwriting process and the BVC instrument that is designed to bring all parties together who include: the site owner, remediation firm, insurer, land planners, entitlement authorities, financiers, and redevelopers into a single, unified set of inter-dependent agreements, at a single point in time before significant capital is invested in the process. The significance of such as system is that it provides liability security to the seller and potential purchaser. In addition, and of great value, is the holistic multi-party approach inherent to the redevelopment process, and the unified well understood goals of decontamination and subsequent redevelopment. Encouraging a trans-disciplinarian approach such as this could integrate and synthesize with ecological remediation strategies, allowing for the potential to fuse multiple site decontaminations within one unified and integrated land reclamation plan.

Conclusions

Urban brownfields provide immense opportunity for beginning a new urban paradigm. Architects, urban designers, planners; all should, or already do recognize the value of idle contaminated urban lands as catalysts for new concepts of urbanism to emerge. Much knowledge is yet to be gained, and continued development of tools and models for brownfield redevelopment such as incorporating and synthesizing ecological assessment models with health and economic models of assessment, as well as perception of place studies, could produce much more inspired land reclamation outcomes.

Phytoremediation

Introduction

A century of mining, manufacturing (industrial and agricultural), and urbanization and its related activities have greatly contributed to extensive global environmental contamination. Remediation of these landscapes has never been more critical than in present day because of the need for developable, agricultural, and civic urban lands. Sprawl continues to swallow undeveloped, ecologically valuable land (greenfields) in the urban hinterlands, creating more pathways for continued environmental contamination and decline. The need for a safe, ecological remediation strategy is urgent not only for improved site scale conditions, but also city and regional scale land planning and preservation.

Current remediation strategies used for organic and inorganic contaminant removal/containment are costly and procedurally invasive. Methods for removing heavy metals (inorganic) include 'dig and haul' (aka excavation and land filling), acid leaching, vitrification, physical separation of the contaminant from soil material, and electrochemical processes (Cunningham *et al.* 1995). All require large energy inputs either from the treatment methodology itself or transport. On small scale urban sites with contamination; excavation, removal, and diposal (so called 'dig n haul') is most often the chosen strategy for brownfield reclamation. This accepted and widely practiced standard enables remediation that merely <u>mitigates</u> a health hazard and is contrary to the very definition of 'remediation'.

Methods for remediating organic contaminants such as VOC's, PCB's, and PAH's include vapor stripping or thermal desorption (for volatiles and semi-volatiles), soil washing (for leachable contaminants), incineration (although not all organic contaminants will burn), and offsite land-filling ('dig n haul') which is again a form of pollution mitigation, where geographic relocation is excused as 'remediation'. In addition to the hyper-invasive and often pseudo-remediating nature of afore mentioned strategies, there is extraordinary fiscal and ecological costs typically associated with them. It has been shown that traditional remediation monetary expenses can range from approximately $60/cubic meter to upwards of multi-thousands per cubic meter for soil remediation (Cunningham *et al.* 1995). This range, and specific costs associated are entirely dependent upon the specific contaminant type, existing soil properties, site conditions, level of decontamination that must be achieved as mandated by land end-use, and volume/concentration of the contaminant on the site.

Beyond fiscal expense, ecological costs are an often overlooked factor in determining a remediation strategy. When considering the ecological footprint of remediation, it is clear that burning fossil fuels (carbon) to clean up carbon (in terms of organic contaminants) is counterproductive. More so, the use of mechanized equipment such as excavators, dump trucks, and numerous other miscellaneous petroleum-burning machines for the removal and transport of hazardous materials greatly increases the immediate hazards of site decontamination because of the potential for particulate drift, direct human and wildlife exposure, and meteorological unpredictability (ie stormwater erosion). Arguably, this is most characteristic of a 'dig and haul' method, but in current society this is the most abundant, accepted, and practiced form of small-scale urban land remediation. Considering the need, and multi-layered costs typifying traditional land remediation strategies, phytoremediation is a very attractive potential technology for urban land reclamation.

Understanding Phytoremediation

Phytoremediation is the use of plants and their associated rhizosphere microflora to remediate soil, sediment, and water impacted by different types of contaminants. It does so by decontamination; removal and/or degradation of organic and inorganic contaminants via integrated biological activities within and/or between plants and associated microbial communities, containment; the stabilization of contaminants by means of soil manipulation and/or vegetative cover to eliminate exposure, and the combined use of both (Lanza and Flathman 2001, ITRC 2001, USEPA 2000). The use of plants to cleanse contaminated water has been used for many years. The treatment of wastewater contamination is well known and is thought to be over 300 years old. Early examples of wastewater treatment include constructed wetlands in the form of reed beds and floating plant systems (Cunningham *et al.* 1995). Only until recently has much attention and progress been made in understanding phytoremediation within the soil environment.

For a clear understanding of the differences between a mechanical systems approach to remediation and phytoremediation, it is helpful to express phytoremediation how Cunningham *et al.* so eloquently describes it: as *'solar-driven pumping and filtering systems that have measurable loading, degrading, and fouling capacities'*. This statement implies not only the plant-media mechanism for effective contaminant treatment, but as well the 'greenness' inherent to it.

The mechanisms by which phytoremediation occurs are phytoextraction; where the contaminant is taken into plant tissue and stored as harvestable biomass, phytodegradation; where the contaminant is degraded from a toxic form into a nontoxic form via internal plant mechanisms or plant-rhizosphere interactions, phytovolatilization; where the contaminant is released into the atmosphere via plant uptake and transpiration, and phytostabilization; where a plant is used as both a chemical and physical containment mechanism for the stabilization of potentially mobile soil contaminants. These four fundamental components of phytoremediation are described and discussed in detail with specific contaminants in later sections.

Phytoremediation as an applied science is still being explored in great depth. In recent years, much research has been done to investigate plant species phyto-toxic capacity for use in phytoremediation, multi-process phytoremediation systems (of which a section of this review will describe in great detail), and the site specificity obligatory with successful phytoremediation.

Monetarily, it has been proven in various field trials that costs associated with phytoremediation are dramatically lower than that of physical and mechanical strategies. Monetary costs range from $.02/cubic meter of soil material to $10/cubic meter. This is a sizeable percentage less than the monetary costs of all other remediation strategies. Figure (1) illustrates a cost comparison done with real cleanup estimates.

FIG. 1

Problem	Phytoremediation Application	Cost ($ thousand)	Conventional Treatment	Cost ($ thousand)	Projected Savings
Lead in soil, 1 acre[a]	Extraction, harvest disposal	$150-250	Excavate and landfill	$500	50-65%
Solvents in groundwater, 2.5 acres[b]	Degradation and hydraulic control	$200 install and initial maintenance	Pump and treat	$700 annual running cost	50% cost saving by third year
TPH in soil, 1 acre[c]	In situ degradation	$50-100	Excavate and landfill incinerate	$500	80%

[a] Phytotech estimate for Magic Marker site (Blaylock et al. 1997).
[b] PRP estimate for Solvent Recovery Systems of New England site.
[c] PERF estimate (Drake 1997)

(USEPA, 2000)

Although this comparison is useful in representing the potential cost savings associated with phytoremediation, cost estimates/comparisons must be done on a site-specific basis. Phytoremdiation projects need to consider the potential for application with specific site conditions (will phytoremediation be successful?), and compare it with the combined fiscal **and environmental costs** of conventional remediation strategies.

Often overlooked in cost estimation but perhaps the most convincing argument for using phytoremediation is the almost negligible, if any, environmental costs associated with phytoremediation. Typically, provisional ecological services are an inherent compliment to phytoremediation. These services can be in the direct form of wildlife habitat, stormwater management, open space (a valuable service in the urban environment), urban forestry, improved air quality, decreased heat island effect from increased evapotranspiration in the urban environment, aesthetic value, and low carbon footprint of implementation. Indirectly phytoremediation in urban environments can provide a potential resource for urban agriculture, community involvement and engagement in the land reclamation process, and post-industrial urban reinvention (ie green jobs).

As highlighted, the advantages of phytoremediation are clear; soil preservation through non-invasive treatment, remediation driven by solar energy suitable to most climates, low monetary and environmental costs, and the potential for rapid remediation with improved methodologies. Limitations of phytoremediation are few and temporary. Much of the recent research has focused on overcoming these limitations that include: overcoming extremely high contaminant concentrations (phytotoxicity), poor soil nutrition and lack of appropriate soil microorganisms, and development of cost estimation models and management/monitoring frameworks. Regulatory issues such as; contaminant bioavailability in the soil not currently being a parameter used in establishing the risk posed by a site, the ability to establish an environmentally acceptable cleanup level based on clear procedures for measuring phytoremediation rates, predicting treatment times, and developing monitoring schemes, are all in need of further clarity. Of great influence for the widespread application of phytoremediation is the current legal landscape that still allows site removal and landfilling of contaminated soil. This typically renders phytoremediation as an unproven, often misunderstood treatment option that could potentially extend party liability. This issue has been recently (2004) addressed in the United Kingdom with the creation of the Landfill Directive and associated changes in waste-acceptance criteria, which has dramatically reduced the number of landfills that will accept contaminated waste from approximately 200 facilities to 11, consequently increasing disposal costs. It is remarkably important to address the issue of contaminant relocation and its validity as an effective 'remediation' strategy in the current US legal/regulatory framework. Although much research in recent years has been paid to improving the application, methodology, and management of phytoremediation, little has been given to the translation and integration of phytoremediation with design. Landscape architects are typically called in after conventional remediation, with little opportunity for exploiting the media (plants, water, earth, etc.) of the profession and proposing planning (urban revitalization) frameworks for redevelopment working within the scientific context of phytoremediation. To this end, phytoremediation has yet to truly connect with people outside of the research, engineering, and academic realm. The landscape architects' primary role is to connect people with things, whether those are physical, cultural, spiritual, systematic, or processes. The confluence of phytoremediation with landscape architecture would enable not only the expansion of design services offered within the profession and the inherent new methodologies obligatory for conceptual development, but as well connect the often misunderstood complex science with the expressive societal milieu and community structure. It is only with this connection that phytoremdiation will have the greatest potential for widespread application. In phytoremediation terms, landscape architects are the metaphorical 'chelators' of the applied science with society; the remediation middlemen.

<u>Phytoremediation of Organic Contaminants</u>

Introduction

Organic contamination in the environment is widespread and abundant. The intentional and accidental release of organic compounds into the biosphere has been rampant in the last century and continues in present day. Commonly found contaminants include poly-chlorinated pesticides (PCP's), poly-chlorinated biphenyls (PCB's), total petroleum hydrocarbons (TPH's), nitro-aromatic compounds (NAC's), polycyclic aromatic hydrocarbons (PAH's), trichloroethylene (TCE), explosives such as TNT, industrial surfactants, and organophosphate insecticides. The origins of these compounds are commonly from industrial and agricultural production, accidental release in the form of spills and unknown leakage, and the byproducts of carbon-based energy production. Risks to human health and the environment are numerous. Particularly toxic and prevalent are poly-aromatic hydrocarbons (PAHs) and have been proven to be mutagenic (having the ability to change the genetic material of DNA in an organism), teratogenic (causing developmental abnormalities such as birth defects), and carcinogenic (cancer causing). The discussion of organic contaminants and associated phyto-mechanisms will focus primarily on PAHs, as it is one of the most common, dangerous, recalcitrant, and difficult organic contaminants' to remediate in non-conventional ways. Phytoremediation in the context of natural attenuation for the decontamination of PAHs will be thoroughly discussed.

Phyto-Mechanisms

To understand how the incorporation of plants aid in the cleansing of organic contamination, discussion of natural attenuation and its relevance is necessary. Natural attenuation is defined by the EPA as:

"The reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more active methods. The 'natural attenuation processes' that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These in-situ processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants." (USEPA, 1999)

Direct natural attenuation of organic contaminants using phytoremediation typically involves hydrophilic (water soluble) organic compounds that allow for transport and distribution within the plant. These processes include phytoextraction, phytodegradation, phytotransformation, phytovolatilization, and rhizodegradation.

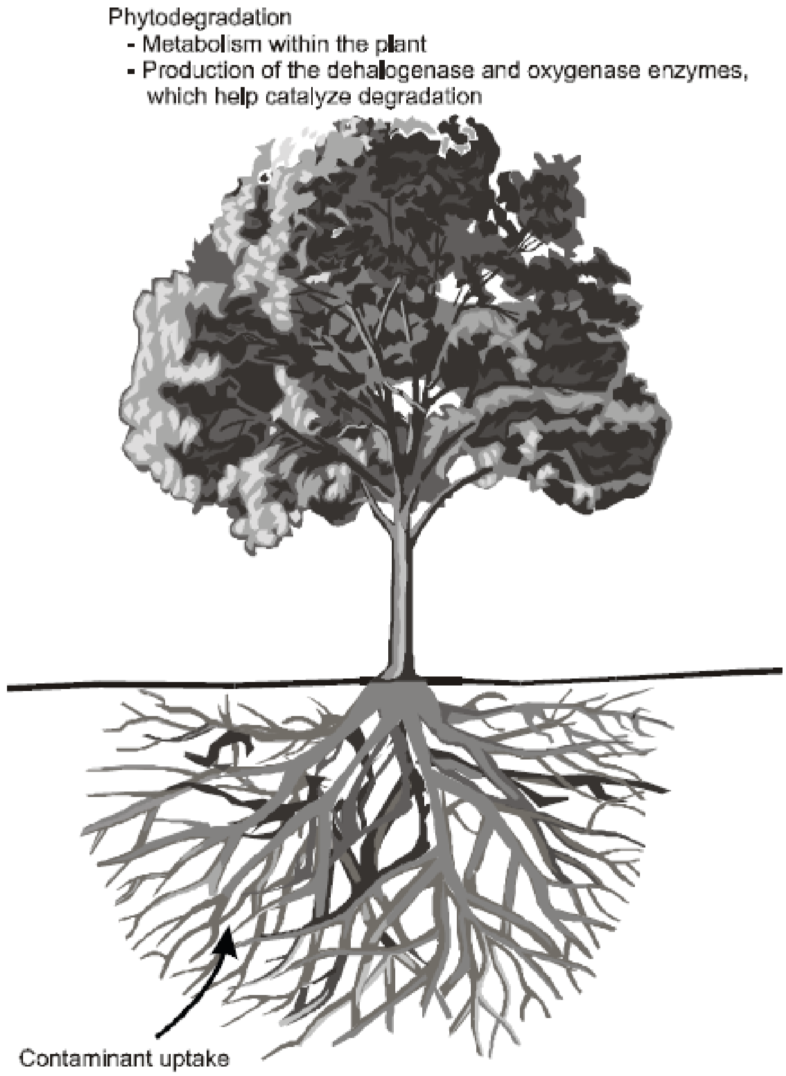
Phytoextraction

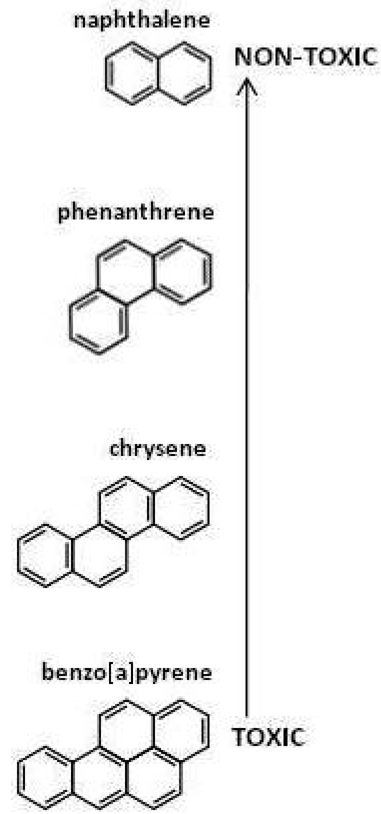
Phytoextraction of certain hydrophilic (water soluble) organic compounds is characteristic of contaminants that are resistant to plant metabolism. This means that the compounds, while mobile in the phloem and xylem of the plant, are unable to metabolize into simpler, less toxic compounds and are stored within the plant tissue. More often, organic compounds are lipophilic (soluble only in oils, lipids, amino acids) and hydrophobic (not water soluble), and phytoremediation becomes a mechanism for indirect natural attenuation involving co-metabolism of contaminants with plant-associated microbes, and plant-induced changes in the contaminated environment (Singh & Jain, 2003) that either change the metabolic potential of compounds for uptake and storage, or break down the compound into a harmless form. For these compounds, the mechanisms of degradation, transformation, volatilization, and rhizodegradation are essential.

Phytodegradation and Phytotransformation

Phyto- degradation and transformation is the process by which contaminants are taken up by the plant, metabolized, and broken down into less toxic or non-toxic compounds within the plant by many metabolic processes of both the degrading compound and plant produced compounds. The combined metabolic processes are analogous with human metabolism of xenobiotic chemicals (those chemicals in an organism that are not normally produced or expected to be present in it), and has been modeled as the "green liver" concept. Figure (2) illustrates the phytodegradation process and degradation train of PAH contaminants and relative toxicity.

FIG. 2





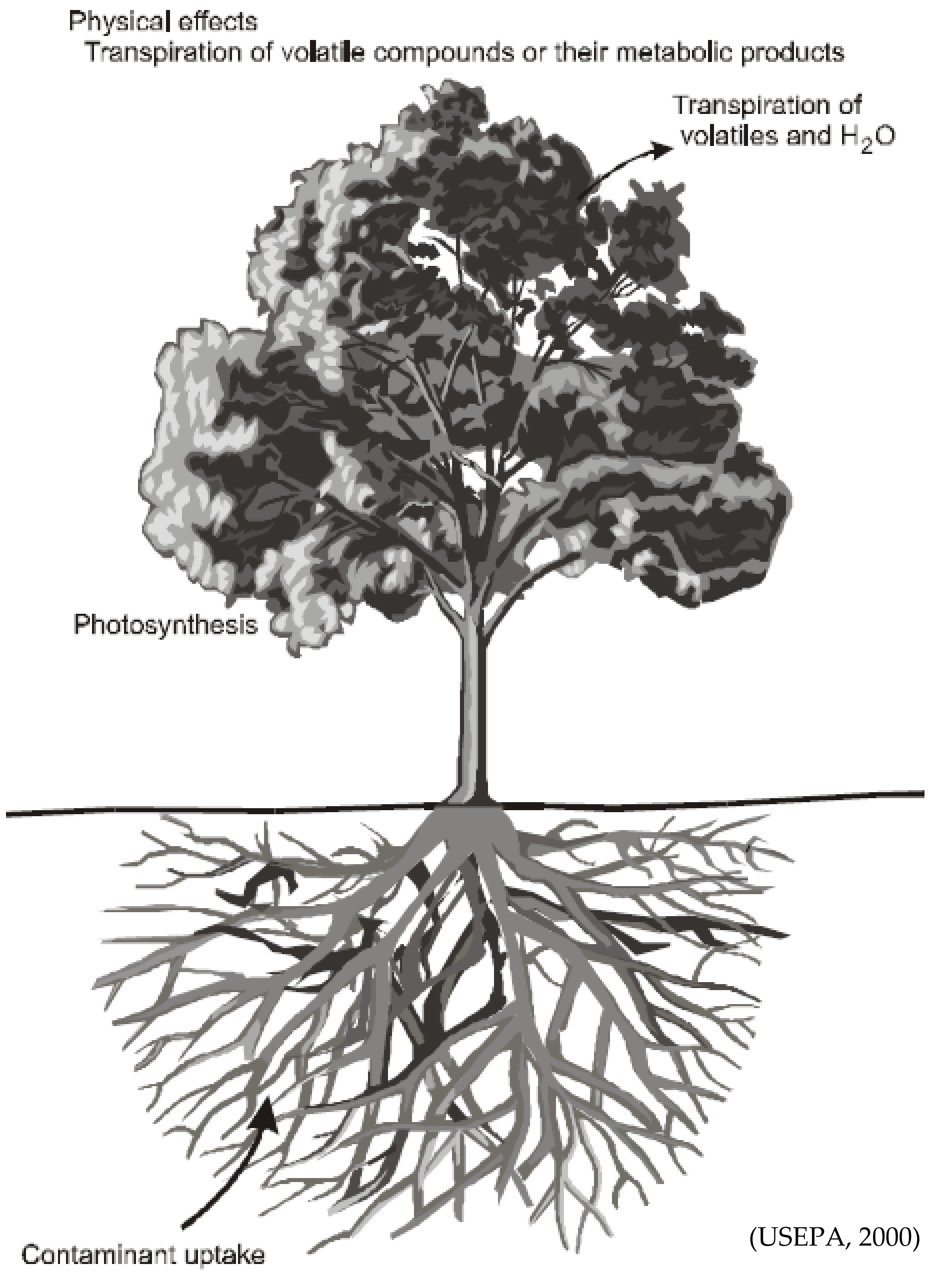
(USEPA, 2000)

Phytodegradation and transformation of hydrophilic compounds is an entirely plant-based metabolic process that can be an efficient and effective means of contaminant removal depending on the specific contaminant and its biological behavior. For example, phytodegradation of TCE within plants is a result of oxidative metabolism by means of numerous plant oxidative enzymes and has been shown to effectively degrade TCE without the aid of rhizosphere microbial communities (Strycharz & Newman, 2009). Extremely hydrophobic and lipophilic compounds have less success at removal and degradation as they cannot be easily translocated within the plant due to strong bonds with the surface of roots and consequently are not sorbed by the roots. Overcoming this will be described in later discussions of the plant-microbe-rhizosphere association.

Phytovolatilization

Phytovolatilization is the process of contaminant (volatile chemicals or their metabolic chemical compounds) release into the atmosphere via plant transpiration. There are certain organic contaminants that persist in the soil sub-surface environment that react rapidly in the atmosphere with hydroxyl radicals (oxidants formed in the photochemical cycle). Very few contaminants are sufficiently water soluble, non-toxic to plants, and volatile enough to reach atmospheric concentrations of concern by evapotranspiration. In addition, it has been shown that certain plants such as the common Red Oak (*Quercus rubrum)* naturally volatize organic compounds as a result of internal plant chemistry, and has shown significant concentrations when assessed as a collective. TCE, PCB's, and TPH's have all been observed to have volatilizing potential, though there is greater need for further investigation into the nature and properties of this remediation mechanism. Figure (3) illustrates the volatilization process.

FIG. 3



(USEPA, 2000)

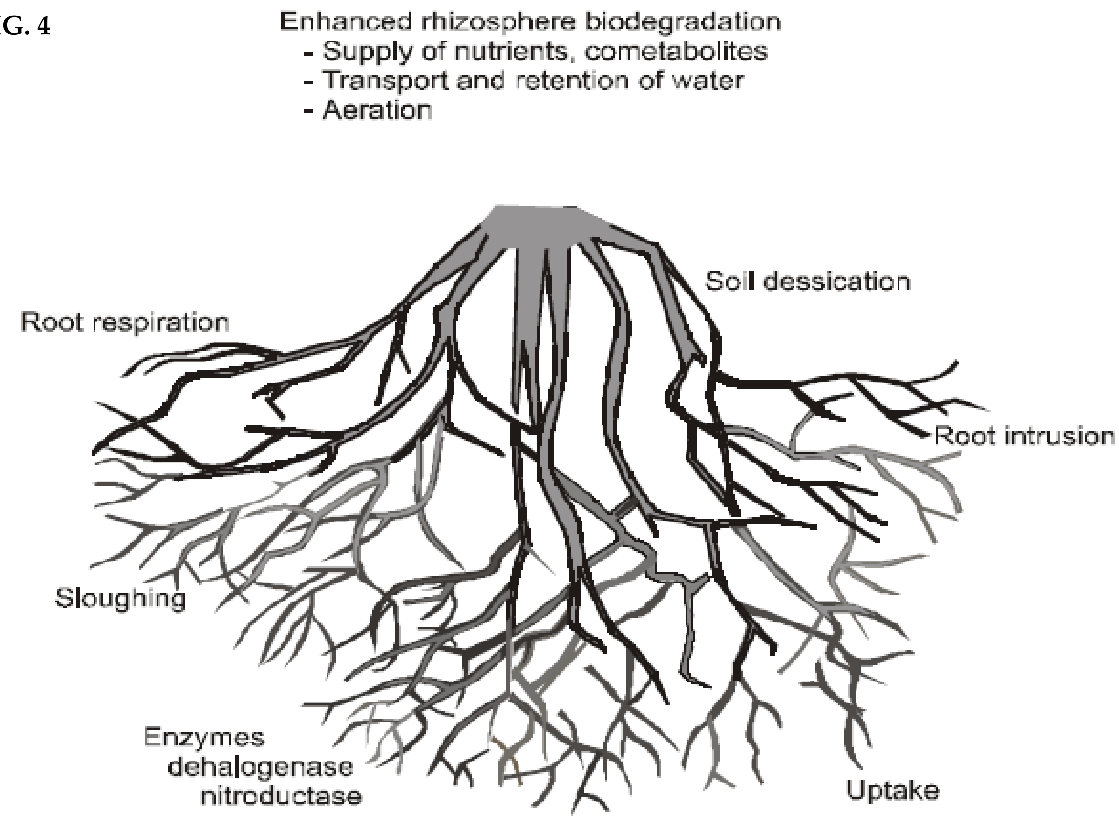
Rhizodegradation

Perhaps the most effective mechanism of phytoremediation is rhizodegradation.

Rhizodegradation (aka' rhizosphere bioremediation' or 'rhizoremediation') transforms contaminants via microbes in the plant rhizosphere. The rhizosphere is the microbe-rich zone that is in intimate contact with the vascular root system of the plant. This dynamic soil environment is under the direct influence of plant roots and typically extends three-to-five millimeters, sometimes more, from the root surface. In the rhizosphere; soil redox conditions, moisture, organic content and other soil properties are manipulated by plant root activity and stimulate microbial development and activity. The stimulation of contaminant removal from the soil is catalyzed by an increase in microbial activity, increased microbe-soil-contaminant association, and chemical and physical changes in soil properties and the rhizosphere. All organic compounds have been shown to have greater degradative capacity within the rhizosphere due to higher microbial activity in the rhizosphere as a result of easily biodegradable substrates such as sugars, organic acids, and amino acids that are exuded from plant roots and serve as a food source for rhizobacterium. It is speculated that the diversity, density and quality of root exudates, caused by the physiological-biochemical differences between plant species determines the mechanisms of removal of soil contaminants. Microbial activity has been shown to be the most influential and significant cause for PAH removal (Cerniglia, 1997), and that plant-enhanced rhizosphere microbial degradation is the most effective primary mechanism for the removal of soil organic contaminants (Reilly et al. 1996, Gunther et al., 2000).

The natural degradation of contaminants is more often the result of microbial consortia rather than by a single microbe pheno- and genotype, but the degradative potential of the consortia is entirely dependent on the individual microbe capability to break down the contaminant (Muratova et al., 2003). Additionally, Sandmann & Loos (1984) proved that the composition of the rhizosphere microbial community is primarily determined by plant species, environmental factors, and 'xenobiotics' present in the soil. Kuiper et al. (2003) added that composition of the microbial population in addition to the composition of the root exudate collective, plant species, plant age, soil type, and soil history are also all important factors. Thus, the determination of the most effective plant(s) species supportive of microbial consortia for the degradation of a specific compound is extremely important (Yateem et al., 1996, Kirsche et al., 1997). Figure (4) illustrates the rhizodegradation process.

FIG. 4



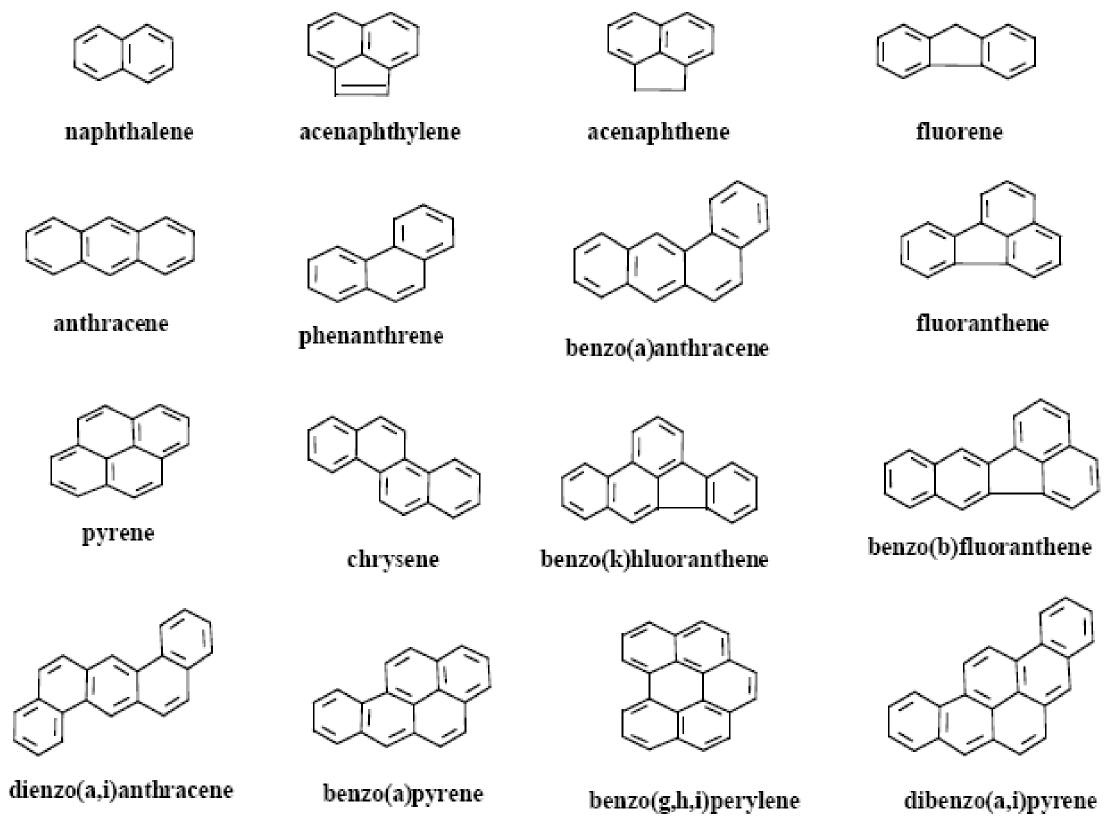
(USEPA, 2000)

Phytoremediation of PAHs

Poly(nuclear)-aromatic hydrocarbons (PAH) are chemical compounds consisting of at least three or more aromatic fused rings and are particularly hard to remediate due to their recalcitrant nature in the soil environment. They are formed during thermal decomposition of organic molecules and their subsequent recombination. Incomplete combustion at high temperatures (500-800 degrees Celsius) or subjection of organic material at low temperatures (100-300 degrees Celsius) for long periods results in PAH production. Although they are the dominant pollutants in the atmosphere, soil acts as the end depository for most PAH compounds. PAH fate in the environment includes volatilization, photo-oxidation, chemical oxidation, adsorption on soil particles, leaching, and microbial degradation. Unlike other organic compounds, PAHs have very stabilized ring structures that make them not easily broken into smaller compounds. They are lipophilic and somewhat hyrdophobic depending on the number of rings (hydrophobicity increases with number of ring structures), and as a result are more commonly found in soils rather than in aqueous conditions. Sources of PAHs include partially-combusted carbon-based products such as coal, wood, diesel, and tobacco. The regulated list of PAHs that pose health and environmental hazards contains 16 compounds, seven of which are known carcinogens, that vary in size, structure, and properties Figure (4).

FIG. 4

Sixteen Priority Polycyclic Aromatic Hydrocarbons



(Huang *et al.* 2002)

Many of the smaller ring structures (<3), and less hydrophobic, can be degraded <u>without</u> phyto-enhancement (rhizo-remediation).

Bacteria catalyze PAH degradation via dioxygenase (any enzyme that oxidizes a substrate by transferring both atoms of molecular oxygen [O_2] onto the substrate) attack which increases PAH chemical reactivity and solubility. Larger ring structures with greater hydrophobicity such as benzo[a]pyrene (5-ring), dibenzo[a,h]pyrene (6-ring), and dibenzoanthracene (5-ring) are highly persistent and bind strongly to organic matter in soil. This strong bond is due to contaminants being trapped into soil pores and immobilized by adsorption (the accumulation of atoms or molecules on the surface of a soil particle, creating a 'film') complicating remediation, and necessitating a multiple technique approach.

Rhizoremediation is the term used for the combination of bioaugmentation (enhanced bioremediation) and phytoremediation. This integration helps to overcome the problems and limitations of each individual remediation mechanism encountered during application, and assists in accelerating remediation time significantly. By supporting and enhancing microbial communities with plant roots and associated rhizosphere processes, greater success and speed can be made in metabolizing small ring structures, which then serve as an additional carbon source during co-metabolic degradation of higher-ringed PAHs (Kuiper et al., 2003).

Small-ring PAHs are also subject to photochemical reactions such as photooxidation (oxidation influenced by radiant energy, such as light). This is significant in that smaller ring compounds when exposed to light can oxidize, break apart, and subsequently provide a carbon resource supportive of microbial degradation of larger ringed compounds not responsive to photooxidation. Design implications of land-farming to exploit photooxidation will be discussed in a later section of this document.

PAHs, Plants, and Microbial Behavior

As discussed, the fate of PAHs in the environment is linked to both biotic and abiotic processes that include bioaccumulation, microbial degradation, and chemical oxidation. Much recent research has been done to study the effectiveness of specific plant species and associated rhizosphere microflora on the decontamination of PAHs in soils. Important to reiterate and a dominant theme in most recent studies, is the variable nature of PAH bioavailability. Bioavailability is strongly affected by both contaminant and soil properties, and the biologically available concentrations of PAHs are typically many times lower than the concentrations of extractable PAHs. The significance of this further illustrates the need for an integrated remediation approach for the successful removal of multiple PAHs from soil where the plant functions not only as a containment device, but also a support mechanism for the rhizosphere micro-ecosystem.

Rezek *et al.* (2009) researched the effects of Red Mulberry (*Morus rubra*) among others, on the degradation of PAHs in the soil. It was shown that mulberry roots release phenolic substances that the study theorized to be involved in various plant-microbe interactions. Although not mentioned, potential effects of increased phenols in the rhizosphere could manipulate the existing pH (phenols are typically acidic in nature), modifying the degradative properties of both the microbial population and subsequent root interaction. (Continued discussion on the influence of phenols on microorganisms will be made in a later section). This is somewhat eluded to in results from experiments using mulberry for the removal of fluoranthene (4-ring PAH). Findings suggest that mulberry interacts with soil degraders either by changing the composition of the degrading consortia, or by the induction or inhibition of a specific degradation pathway that changes the degradation properties of the rhizosphere micro-ecosystem. Collectively, Rezek *et al.* researched the effects of plant-microbe degradative capacity for 15 compounds using European birch (*Betula pendula*), mulberry as mentioned, and perennial ryegrass (*Lolium perenne).* All compounds except for benzo[ghi]perylene and indeno[1,2,3-cd]pyrene showed significant signs of contaminant degradation. After 18-months, concentrations of fluoranthene fell significantly to 27% of the original concentration. In that same time period, benzo[a]pyrene (one of the most monitored compounds due to its highly carcinogenic nature) showed a 70% decrease in concentration from the original. This is quite significant degradation in a very small time frame. Rezek *et al.* enunciated that time is a major factor in microbial development and consequential degradation potential. This most likely is attributed to varying growth rates of juvenile plant material used. Similarly, Godsy *et al.* proposed that as trees age the microbial populations have the potential to change and foster anaerobic degradation. In the Rezek et al. experiment, young mulberry specimens exhibited stress in contaminated soils in the first twelve months, consequently having decreased root biomass and little degradation supportive capacity. Due to the slow growth rate inherent to mulberry, this was not surprising and was accounted for in the methodology of the experiment, allocating a single harvest and analysis after the full 18-month research period. European birch does not exhibit similar growth characteristics to mulberry and showed better health and produced higher biomass in only 12-months. Collectively in 18-months, PAH concentrations dropped to almost negligible levels. This challenges the argument of phytoremediation being too long term a strategy for adoption. That being said, Rezek *et al.* did show seasonal stall in microbial activity and slowed degradation rates after 12 months (the final 6 months fell in fall and winter). This is not surprising, and actually strengthens the relatively short term efficacy of the results.

In other studies evaluating plant-microbe interaction for the degradation of PAH, Chen *et al.* showed a 38% and 30% pyrene mineralization in tall fescue (*Festuca arundinacea*) and switchgrass (*Panicum virgatum)* respectively, compared with 4.3% in an unplanted control. This too elaborates on the effectiveness of phyto-assisted microbial degradation. Muratova *et al.* (2003) experimented with alfalfa (*Medicago sativa*) and reed (*Phragmites australis),* and showed that both successfully remediated PAH-contaminated soil by degrading 74.5% and 68.7% respectively. The study also showed a measurable increase in the number of soil microorganisms (~1.3 times more than without vegetation), and the rate of the PAH-degrading populations had a seven-fold increase.

The significance of alfalfa being a successful phytoremediator, beyond its contaminant removal capacity, lies with its potential to be grown as a marketable crop (ie horse feed, etc.). Singh & Jain (2003) discussed the use of industrial hemp (*Cannabis sativa*) for remediation of PAH-contaminated soils containing benzo[a]pyrene and chrysene in which hemp showed an extremely high tolerance to the contaminants and was successful at significantly reducing levels of both PAH compounds investigated. This again portrays the potential multi-functionality of phytoremediation of organic contaminants. The integration of agricultural production with phytoremediation and its potential for fiscal recycling to moderate remediation costs will be further explored in the design section of this document.

Although phytoremediation of PAH-contamination in soil has been proven successful, measuring plant effects on PAH degradation remains difficult, and consequently measuring phyto-treatment effects is confronted by numerous interactions within the soil-rhizosphere-microbial-plant system (Newman & Reynolds, 2004). The complexity of understanding and monitoring these interactions is due to inherent variables such as moisture, temperature, and growth stage of both plants and microbes. This coupled with the behavior of fundamental agronomic components such as C:N ratio, (which can be affected by hydrocarbon-based compounds and consequently lead to nitrogen immobilization), and the contaminant-soil-plant-nutrient interaction can increase implementation complexity and create experimental management and monitoring strategies for site specific conditions.

Phytoremediation of Inorganic Contaminants

Introduction

Heavy metal contamination accounts for 40% of the contamination found on sites identified in the EPA's 1986 National Priority List. Unlike organic contaminants, inorganic contaminants cannot be broken down into less harmful components, making it necessary that they be removed from, or stabilized within the soil. Phytoremediation of inorganic contaminants uses plants to stabilize, filter, accumulate, and volatize contaminants and has been shown to be an effective, non-invasive, inexpensive, aesthetically pleasing and socially accepted technology to remediate heavy metal polluted soils (Weber et al. 2001; Garbisu et al. 2002). The use of plants in the treatment of soil inorganic contamination is a recent practice, and historically has been used as ore mining indicators due to their known ability to survive and/or absorb certain metals. These sites have been informative for identifying and analyzing plants of potential significance for the intentional removal of metals.

The specific discussion of inorganic contaminants and the use of phytoremediation for removal from soil will primarily focus on lead (Pb), as it highlights some of the challenges associated with the removal of most heavy metals (not metalloids, which have dramatically different soil behavior). The discussion will focus exclusively on removal from soil media, as this is the greatest environmental storehouse for this extremely abundant and persistent contaminant in the biosphere.

Remediation alternatives for addressing this widespread contaminant are few. Soil and water washing have been shown to be effective, as well as 'dig and haul' (physical removal and transport to treatment facility/landfill), soil flushing and vitrification. All are costly, limited in their applicability, and/or pose additional environmental risks. The need for cost-effective, non-invasive remediation strategies is urgent. Phytoremediation shows great promise for removing and/or stabilizing dangerous levels of lead in soil, sediment, and water.

Lead in the Soil Environment

Naturally occurring levels of lead in the soil environment range from 1 – 200 mg/kg. Risk assessment studies have proposed a maximum soil Pb concentration of 300 mg/kg (Dudka and Miller, 1999). The EPA recommended soil threshold is 400 mg/kg (USEPA, 2001). Higher concentrations of lead can become an extremely persistent contaminant in soil (Elles and Blaylock, 2000). This is mostly due to the formation of insoluble precipitants (precipitation is the formation of a solid in a solution during a chemical reaction), making it less soluble and immobile. Other factors influencing the mobility of lead are pH, soil texture, clay mineral type and concentration, % organic matter, cation-exchange-capacity (CEC), and drainage. The poor bioavailability of lead (Pb2+) is the greatest obstacle for a phytoremediation strategy to be successful. It has been shown that only 0.1% of total soil Pb is available for extraction and is immobilized in soil by complexation with organic matter; precipitates as carbonates, hydroxides, phosphates and oxides; and sorbs on clay and oxide particles (McBride, 1994). In soils supportive of plant growth, soluble lead is minimal due to these strong bonds with soil minerals and organic matter and little, if any uptake by the plant occurs even if the plant has the toxicity capacity to tolerate the metal. Additionally, if plants are able to attain some lead in their roots, they are still unable to transport lead to the aboveground harvestable plant portions due again to complexation with plant nutrients making phytoremediation a much more laborious and costly strategy. Therefore, it is important to find ways to enhance the bioavailability of lead, or to find specific plants that can better translocate the lead into easily harvestable biomass.

Given the excessive difficulty of plant accessibility for uptake and translocation of lead, aqueous solutions containing chelating agents are applied to soil in order to mobilize lead and facilitate extraction. The most widely used chelator is EDTA (ethylene diamine tetra-acetate). EDTA, in concert with various acidifying soil materials, has been shown to be the most effective chelator for enhancing lead translocation from roots to shoots (Wu et al, 1999), and increasing the solubility of lead in soils. Though effective in its ability to mobilize lead allowing for uptake and removal from the soil medium, EDTA application at high rates can increase the potential for groundwater contamination due to accelerated metal mobilization and resulting uncontrolled leaching (Wenzel et al., 2003). In addition, rapid, poorly timed releases of EDTA could elevate short-term metal concentrations resulting in phytotoxicity of juvenile plantings, drastically reducing the growth rate and decreasing the efficacy of remediation. Recent research shows much promise in how to improve the efficiency of EDTA application and minimize its quantities in the soil environment while still maintaining effective phytoextraction (Saifullah et al., 2009). Barocsi *et al.* (2003) experimented with incremental applications of EDTA and compared the effects with single dose application to *Brassica juncea* (Indian Mustard). Extreme phytotoxicity was a result of single dose application, while incremental applications of 4 mmol/kg showed little to no toxic effects on plant material. It was also shown by Shen *et al.* (2002) that incremental applications both increased plant shoot concentrations of Pb, as well as reduced leaching in the soil environment. Blaylock et al. (1997) showed that the addition of chelators was most effective when applied to established plants several days before harvest. This not only mobilized the inorganic target contaminant for uptake, but as well minimized the period in which the stored metals would be accessible in the food web.

In addition to chelating agents, agronomic techniques can be effective at decreasing the pH of the soil that aids in increasing the bioavailability of metals for plants (Harter

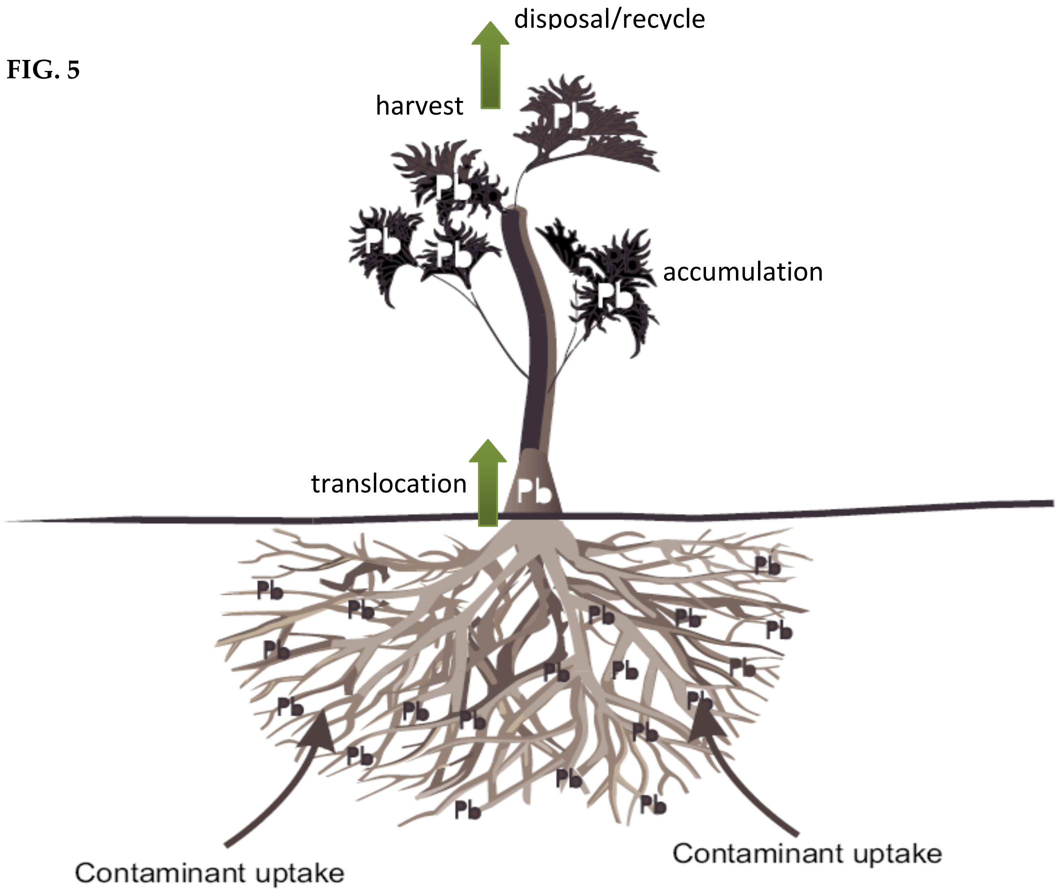
1983). Soil pH is a critical component in Pb availability. Chlopecka *et al.* (1996) researched the effects of soil pH on lead uptake and found that slightly acidic soil was beneficial to both availability of metals (more specifically Pb), and translocation of lead into the roots and shoots of the plant. The study concluded that the optimum pH for promoting exchangeable Pb, as well as increased translocation was between pH 5.0-5.6. This has multiple implications. First, plant material must be amenable to lower pH soils, as healthy plant nutrient retention and uptake is entirely dependent on pH. Second, the methodology for phytoremediation of Pb has to be holistic and multifaceted. This would involve the use of soil amendments in concert with low-dose well-timed chelate applications, and appropriate hyperaccumulators for maximum remediation efficacy. Although lead has been the primary metal of focus in this discussion, the key factors such as soil pH, soil structure and soil properties all greatly influence the capacity for plants to remediate any particular metal. Some metals, such as nickel (Ni) are more mobile and readily accumulated. Again, this greater mobility and uptake is entirely dependent on soil pH. Also implicit in metals with higher mobility is the potential for phyto-toxicity, where plant uptake exceeds its capacity to tolerate and process excessive metals. Hyperaccumulators are effective, but they have their limits.

Plant Mechanisms

Phytoextaction

Phytoextaction is the uptake and containment of contaminants, particularly toxic metals by plant roots and the translocation of these contaminants into plant biomass including plant shoots, foliage, and woody tissues. Specialized plants known as hyperaccumulators, extract and accumulate very high levels of contamination from soil. Contaminants within the plant biomass can then be recycled or disposed of with little physical impact on the site while still achieving regulatory levels of remediation suitable to land end-use. Figure (5) illustrates the phytoextraction mechanism:

FIG. 5



(USEPA, 2000)

The effectiveness of phytoextraction of Pb is subject to both the level of concentration in the soil, and the biomass yield potential of the phytoextractor. A higher yield plant will extract and translocate higher levels of contaminant. Plants also need to have a baseline tolerance to the contaminant. Through observations of contaminated sites and species exploiting the conditions, early researchers tested plants suspected of high contamination tolerances. These plants were then established as hyperaccumulators, based on the relationship between metal concentrations and the level of potential accumulation in plant tissues. Relative to Pb, the background concentration of lead in plant tissue is 10 mg/g; therefore the hyperaccumulation of lead is defined as >1000 mg/g. Species tolerant of contamination and shown to be successful hyperaccumulators for the removal of Pb are the following:

Armeria maritima	*Myriophyllum spicatum*
Ambrosia artemisiifolia	*Pelargonium sp.*
Brassica juncea	*Thiaspi alpestre*
B. napus	*T. rotundifolium*
B. oleracea	*Triticum aestium*
Festuca ovina	*Typha spp.*
Helianthus annus	*Zea mays*

The list continues to evolve with new research into improving the efficiency of inorganic phytoremediation.

Rhizofiltration is the extraction of metals from aqueous solution (groundwater) (Flathman and Lanza, 1998) and typically involves plant species with high hydraulic control (prone to process large quantities of water) such as willow and poplars. This has been shown to be a much less costly remediation strategy for groundwater contamination then typical pump and treat methods where groundwater is pumped above ground, treated and cleaned to safe levels, and reintroduced into the watershed. The mechanisms and energy required for large scale groundwater remediation using a pump and treat method are excessive. It is only with the use of plants that cost-effective and successful filtration of this common environmental pollution can take place.

Phytostabilization

Phytostabilization is the use of plants coupled with agronomic techniques to stabilize pollutants in contaminated soil. This is particularly effective for the stabilization of lead in soil. A cocktail of soil amendments such as biosolids, mineral oxides, and additional organic matter has been shown to render lead more insoluble and unavailable to leaching, wildlife ingestion or plant uptake. It has also been shown that plant roots can immobilize stabilized lead contaminants in soil, reducing the environmental risk. Phytostabilization also eliminates the need for disposal of hazardous biomass, characteristic of phytoextraction (Flathman and Lanza, 1998). The determination of which phyto-strategy is most effective is based on the characteristics of the specific site such as levels of concentration, soil characteristics, future land use, and environmental exposure in remediation.

Conclusions

The complexity of lead removal using phytoremediation is formidable and site specific, and is only now beginning to be understood. Although an evolving technique, regulatory acceptance of phytoremediation exists and is promoted by the EPA for large scale and often hugely expensive cleanups. Disadvantages of phytoremediation of inorganics and its application include the limitations of hyperaccumulators to only be effective for singular contaminants. This can create complications based on multiple contaminants typically found making a hazardous heterogeneity in the soil. This can add extreme complexity to a phytoremediation strategy due to varying contaminant type and soil behavior. Biomagnification can also become a potential hazard of inorganic phytoremediation in that it creates a vector for contaminants entering the food chain. Hyperaccumulators typically have slower growth rates and low biomass which can extend the active remediation time, but with proper agronomic techniques and the addition of amendments and supplements such as plant growth promoting rhizobacteria, fungal inoculants, and other amendments this can be overcome with obvious additional costs and labor.

Phytoremediation of lead is perhaps the most effective method of remediation currently available. Based on the limited existing alternatives, it has been shown to be cost- (fiscal and environmental) effective and successful for the removal of elevated levels of lead in the biosphere. Much progress must still be made in developing holistic, integrated technologies and application strategies, but it has been proven as a powerful remediation alternative.

The use of plants as temporal form and spatial structure, the agronomic methodology used for remediation control, and the potential for continual redesign as science dictates, all integrate the temporal spatial experience; implementation and construction;

management; planning; and subsequent monitoring, and offer great opportunity for new design processes to emerge. The discussion of inorganic contaminants, specifically lead (Pb) highlights the need for a more specialized approach in design; one that explores how emergent temporal scales such as human time in the experience, remediation time, monitoring schedule, soil input/amendment timing, harvest timing, and how this cumulative temporal flux can influence a malleable land use in the long term by people's unconscious spatial acceptance of it as being such. Spatial evolution can synthesize with this temporal scale and continually react and provoke new expression and experiences that form a characteristic and unique landscape typology in multiple scales.

Multi-Process Phytoremediation System

Introduction

The future of applied phytoremediation and its successful widespread adoption relies on, among other things, the integration of multiple treatment processes and creation of a unified remediation system. Research has proven that it is nearly impossible to use a single technique to rapidly and completely remove multiple contaminants. By combining multiple strategies and optimizing each individual remediation process, the overall efficacy can be greatly improved in all. Consequently, the time required for the removal of persistent contaminants from soil can be significantly shortened (Huang *et al.* 2004). A multi-process phytoremediation system (MPPS) will be discussed in the context of PAH decontamination. Discussion of PAHs in this context will not only supplement earlier review, but as well serve to effectively make the case for a multi-process approach based on the variable and complex nature of compounds within this category of organic contaminants. Huang *et al.* experimented with four techniques, both individually and in various combinations, for the removal of PAH's from soil. Techniques used include land farming, light exposure, microbial inoculation, and phytoremediation with the use of plant-growth-promoting-rhizobacteria (PGPR). Using these techniques, resulting remediation processes include volatilization, photochemical oxidation, microbial degradation, and phytoremediation, respectively. The implications on landscape architecture using an MPPS approach are profound and most promising for the development of new design systems, conceptual processes, and ongoing design dialogue in multiple scales. In the very current context of ecological urbanism; urbanism that seeks a need for adaptation and resiliency, this approach and inherent design modification while in a spatially and temporally dynamic land use, engages remediation as an ongoing spatial and cultural opportunity and event, rather than a necessary annoyance of one-time redevelopment. Further discussion of this will be made in the design discussion section of this document.

Land-farming

Land-farming involves the physical manipulation of contaminated soil so as to aerate and expose contaminant compounds to both oxygen and light, respectively. In doing so, the soil media is 'farmed' back to a non-toxic state while increasing soil redox potential resulting in increased contaminant degrading microbial populations. In situations where contaminants are buried in the soil sub-surface beyond the reach of plant root biomass, careful excavation, subsequent tillage, and scheduled physical manipulation can be extremely effective in staging remediation processes for subsequent MPPS phases. Land farming is a remediation technique that is supportive of volatilization and photo-oxidation processes. In an MPPS framework for remediating low molecular weight PAHs (< 3 ringed PAHs), it is the initial process implemented for rapid removal of easily volatized compounds such as naphthalene, acenaphthene, and acenaphthylene. Compounds such as fluorene, phenanthrene, and anthracene which do not readily volatize decrease as a result of photo-oxidation. Experiments done by Huang *et al.* using land farming (alone) reduced PAH levels in soil 35% over a period of 120 days. Remaining PAHs primarily consisted of higher weight compounds (4, 5, and 6-ring PAHs) that are not readily volatized or photo-oxidized. (Picado *et al.*, 2001) showed similar results with a 79% decrease of 2, 3, and even 4-ring PAH compounds after 3 months, while 5 and 6-ring compounds decreased only 18% over the same period most likely as a result of increased soil microflora and specific adaptation of degrading colonies to specific PAH compounds (in this case, pyrene and phenanthrene). Additionally, Picado *et al.* determined that the microbiological evolution pattern clearly followed PAH removal. This was observed in soil samples showing a change in microbe population composition. Initially, no pyrene and phenanthrene colonies were detected, but between two and four months a significant increase both in the colonies total number and in specific pyrene and phenanthrene degrading colonies was observed. Picado *et al.* concluded that microbial growth was relative to the level of PAH utilization as a substrate. In long term experiments, Bossert *et al.* showed an 80-90% PAH reduction over three years. Harmsen *et al.* added that land-farming PAHs is a two-step process involving; 1. <u>Intensive treatment:</u> in which readily available contaminants are removed, and 2. <u>Extensive treatment:</u> where poorly available parts of contaminants are removed. Optimization of these two steps could be done through biostimulation or bioaugmentation, or the combination of both, especially for the removal of large-ringed PAHs.

Huang *et al.* tested land farming in combination with other individual remediation techniques including microbial inoculation and phytoremediation to identify the variable efficacy and differences in each combination. After 120 days, land farming in combination with only microbial inoculation showed a 50% reduction in PAHs, while land farming combined with only phytoremediation showed a slight increase in PAH removal at 55%. Huang *et al.* suspected that this slight increase was a result of phytoremediation and associative rhizosphere activity being more effective for the removal of larger-ringed strongly soil-bound PAHs.

Land farming as a singular strategy is primarily most effective for the removal of easily volatized and oxidized organic contaminants and has little direct effect on the removal of inorganic contaminants. Indirectly, land farming can be effective for inorganic contaminant removal by enabling availability for removal and uptake by hyperaccumulators in situations where contaminant depth does not allow for effective plant sequestration. In terms of landscape architecture and spatial design, land-farming would support the manipulation of landform for both effective remediation and space definition. As the initial phase in a multi-phase system, the opportunity for staged and dynamic design experiences is great and could be inclusive in the planning strategy for adaptive site redevelopment.

Microbial inoculation

Successful *in situ* remediation of PAH-contaminated soil is largely a result of microbial digestion and catabolic action. Specific PAH-degrading microorganisms can be algae, bacteria, and fungi, and typically involves the breakdown of compounds through biotransformation into less complex (less toxic) metabolites and mineralization into inorganic minerals via enzymes such as oxygenase, dehydrogenase, and lignolytic enzymes. Degrading colonies are often found in, and harvested from long-term petro-chemical waste harbors in the environment and then cultured and enriched in lab conditions for reintroduction into contaminated media for controlled remediation (Haritash & Kaushik, 2009). The use of native microflora is preferential in that these microorganisms are expected to be more adapted to the specific soil environment than non-indigenous commercial microbial inoculate and would most likely out-compete introduced microorganisms. However, when native species display less efficient/effective degradation, augmentation using introduced microorganisms may be necessary to fulfill desired remediation goals in a given period of time (Silva *et al.*, 2009). Much research has been done on identifying site specific strains for bioremediation of contaminated sites. Aitken *et al.* isolated 11 strains from a variety of contaminated sites containing contaminants such as oil, motor oil, wood treatment chemicals, and byproducts of the refinery industry that have the ability to degrade benzo[a]pyrene. Species identified include three species of *Pseudomonas*, as well as *Agrobacterium, Bacillus, Burkhdderia, and Spingomonas* species. Other studies done on the biodegradation of benzo[a]pyrene, show *Rhodococcus sp., Mycobacterium,* and <u>mixed cultures</u> of *Pseudomonas* and *Flavobacterium* to be successful degraders. In research to evaluate specific species for the degradation of pyrene, Heitkamp *et al.* and Rehmann *et al.* both showed pyrene mineralization and utilization, respectively, by isolated strains of *Mycobacterium*. Rehmann *et al.* added that pyrene was the primary source of carbon and energy for the *Mycobacterium* strain KR2, which was isolated from a PAH-contaminated soil. Rehmann *et al.* observed the isolate to metabolize 60% of the added pyrene in 8 days at 20 degrees Celsius. Additionally, degradation products were identified and included C15-4,5-pyrene dihydrodial, 4-5 phenanthrene dicarboxylic acid, 1-hydoxy-2-naphthoic acid, phthalic acid, and protocatechuic acid. The significance of identifying degradation products is to inform the degradation pathway of specific compounds. This can be extremely helpful for understanding the evolution of soil chemistry in a remediation environment and inform potential effective monitoring and assessment methods, and proper intervention and timing within a multi-process framework as a stage in designed succession. Dean-Ross *et al.* conducted similar experiments in which the degradation pathway of fluorene was identified using *Mycobacterium* and *Rhodococcus sp*. In both strains, metabolism of fluorene occurred on the fused ring of the fluorene molecule, producing 9-fluorene-1-carboxylic acid. Understanding degradation pathways is critical for successful managed remediation within an MPPS framework. In real-world conditions where multiple contaminants in varied concentrations and soil conditions exist, knowledge of individual compound degradation behavior and subsequent effect on other individual compounds as well as the contaminant collective is crucial. Consequently, designed microbial consortia must be tailored to create non-inhibitory (to the collective) behavior during and/or after metabolism and digestion. This sensitivity is highlighted in experiments done by Stringfellow and Aitken, where competitive inhibition was observed in two strains of *Pseudomonas* species when degrading PAH-contaminants. They found that the presence of phenanthrene inhibited the degradation of pyrene. Similarly, degradation of anthracene by *Rhodococcus spp.* and pyrene degradation by *Mycobacterium flavescens* has been shown to be inhibited by the presence of fluorene in soil. Contrarily, in studies with pure denitrifying isolates (bacteria that reduce nitrates or nitrites to nitrogen-containing gases; a major process in cycling nitrogen) the presence of naphthalene <u>enhanced</u> both phenanthrene and pyrene degradation. In experiments done with pure cultures of *Pseudomonas putida* strain KBM-1 in various mixtures of PAH compounds under aerobic conditions, the presence of naphthalene stimulated phenanthrene and pyrene degradation 5- and 2-fold, respectively. Concurrently, Yuan *et al.* proposed that the degradation efficiency of microorganisms is more vigorous when acenaphthene, fluorene, phenanthrene, anthracene, and pyrene are present simultaneously compared to the rate of degradation when present individually due to the increased carbon source as a result of multiple compounds and/or cross acclimation enhancing the rate of degradation. It is very difficult to be certain as to the outcome of contaminant degradation using microbial cocktails. This is due to the variable nature of soil contaminant mixes, soil moisture, soil temperature, and the microbial consortium behavior and response to soil-pH. Soil-pH is perhaps the most critical factor for the efficient degradation of PAH-contaminants by microorganisms. A slight pH shift in the soil from 5.2 to 7.0 has been shown to dramatically affect the rate of degradation. Neutralization of soil (pH-7.0) at 30 degrees Celsius is generally favorable for microbial survival and subsequent degradation potential.

Much research in recent years has shown definitive evidence of effective PAH remediation using microbial consortia inoculate. Factors that influence success are site specific and extremely complex. The use of indigenous microflora is always preferential and should involve preliminary lab analysis before implementation to gauge specific degradation pathways, potential, and capacity. As a singular remediation strategy, microbial inoculation is only as effective as the site conditions allow it to be. This being said, the determination of success is defined narrowly and allows for minimal flexibility in methodology and implementation. In addition to the extreme complexity of inoculation alone, the variable results and debatable outcomes often further complicates the level of regulatory compliance expected for individual sites. In this light, microbial inoculation as a component in a multi-process phytoremediation system is most promising as it can adopt a level of malleability to define success. When combined with the initial MPPS component of land-farming, it can serve as not only the 'polisher' for incomplete remediation processes carried out in volatilization and photo-oxidation of higher weight PAH compounds, but also serve as the precursor for enhanced phytoremediation, enabling a rhizosphere preparatory stage in the MPPS collective. In phytoremediation alone, one of the most inhibiting factors of success is a stressful soil environment and resulting phytotoxicity. Although not entirely healing in this way, microbial inoculation can support the creation of a more conducive rhizo-environment allowing for greater success in the decontamination of PAH-contaminated soils using plants as the final cleansing stage in the system. In addition, the introduction of characteristic indigenous soil microorganisms can initiate the development of productive soils in the urban environment supportive of more 'natural' successional patterns and processes over time that would have most likely been absent in the urban rhizosphere had the opportunity for remediation and recovery not existed.

Phytoremediation using Plant-Growth-Promoting-Rhizobacteria (PGPR)

Plant-growth-promoting-rhizobacteria (PGPR) is a term to describe the microorganism collective that colonize plant roots, and in doing so, aid plant growth and reduce susceptibility to pathogens and/or insect damage. They do so primarily as a result of plant hormone modification and enhancement via release of enzymes such as 1-aminocyclopropane-1-carboxylic acid deaminase which consumes the immediate precursor to ethylene, a senescence-promoting chemical and stress hormone that slows plant growth (Glick, 2004). Additionally, PGPR aids in the production of the primary plant hormones, auxin; which controls and promotes root cell development, and cytokinens; which aids in cell elongation and promotes shoot and stem development. Typically, application of PGPR inoculants is isolated to commercial crop production as a means to minimize pesticide use and promote larger yields for greater profit and decreased environmental decline resulting from applied long-term management inputs. PGPR and its use, has been proven as a formidable component for sustainable agriculture and the future of worldwide agronomy. Though effective as a biostimulant and pest/pathogen controller, artificial propagation and subsequent storage and maintenance while in transit from lab to field for widespread application can be tricky. Seed inoculation is the standard and most often used method of application, and has proven difficult due to numerous factors including the ability to survive inoculation onto the seed, to multiply in the spermosphere (region surrounding the seed) in response to seed exudates, to attach to the root surface, and to colonize the developing root system (Nelson, 2004). Recent progress in developing successful methodologies for seed inoculation and subsequent rhizosphere survival and procreation has showed great promise for widespread application and use, yet mortality as a result of predatory indigenous soil and rhizosphere microflora is still being researched for a solution.

In terms of phytoremediation, the greatest benefit of PGPR inoculation is the promotion of larger root biomass for maximum contaminant accumulation (inorganic) and increased microbial populations resulting from a larger host (plant roots). Additionally, the suppression of ethylene production as a result of enzymatic influence greatly reduces plant phytotoxicity (in both inorganic and organic contaminants) and consequential slowed growth effects currently inhibitory to applied phytoremediation. In experiments done by Rugh *et al.*, 18 different plant species native to Michigan were tested to evaluate their degradation capacity of PAHs. It was found that the indigenous rhizobacteria stimulated biodegradation of a much broader range of PAH compounds as compared to unplanted soil bacteria consortia. The value of this is significant. Firstly; native plants as phytoremediators is immensely important for the successful widespread, multi-geographical application of phytoremediation as a land decontamination strategy, and secondly; the ability to potentially acquire, culture, and systematically inoculate native plant species with pre-acclimated indigenous rhizobacterium strains is absolutely necessary for increasing remediation efficacy and decreasing remediation timeframes. The experiments of Rugh *et al.* establish implicit conclusions regarding the ability for increased species selection for phytoremediation as a direct result of the potential for decontamination via the associated rhizosphere bacterial community. Implicit in this as well, is the necessity for a multi-process systems approach to phytoremediation for not only maximum decontamination efficacy, but as well the opportunistic expansion of the phytoremediative plant palette. Complimentary to these findings, is research done by Radwan *et al.* that explored the hydrocarbon utilization potential of nitrogen-fixing nodule bacteria in concert with PGPR. The results showed that legume (species within the family Leguminaceae) crops are suitable for the degradation of multiple hydrocarbons, including aliphatic and aromatic compounds (PAH), and in addition provide rich sources of carbon to further support microbial consumption and subsequent degradation. Significantly, the C:N (carbon to nitrogen) ratio is maintained even with the increase in carbon by the nitrogen fixing behavior of the nodule bacteria, thus overcoming a common obstacle of nitrogen immobilization and loss of bioavailability in hydrocarbon-contaminated soil. In similar studies done by Dashti *et al.* (2009), legume crops not only supported rhizospheric hydrocarbon-utilizing microorganisms, but also more efficient hydrocarbon mineralization by nodule diazotrophic bacteria. Results proved that hydrocarbon-contaminated sandy soils poor in nitrogenous compounds could be effectively fertilized without additional fertility inputs providing economic and environmentally advantageous phytoremediation management.

The discovery and exploration of both native plant species and nitrogen-fixing plant species for use in a multi-process phytoremediation system is in its infancy. Continued exploration of applicable species based on indigenous characteristics as well as self-fertility properties in combination with contaminant degradation potential is critical for the further development and refinement of applied phyto-technology. Numerous plant families native to the northern hemisphere have nitrogen-fixing properties such as in the family Myricaceae (of which the woody shrubs Northern Bayberry (*Myrica pennsylvanica*), Sweet Gale (*Myrica gale*), and Sweet fern (*Comptonia peregrina*) are a part of) and could, if proven, significantly increase the functional palette of phytoremediators for the decontamination of many organic compounds in soil. Increased plant palette in addition to dynamic systems design is wonderfully opportunistic for landscape architecture to begin a new land reclamation paradigm, one that embraces and exploits the science of environmental cleansing and recovery, while conveying a new cultural landscape phenomenon that connects people with processes and emergent patterns.

Conclusions

The use of a multi-process phytoremediation system has been explored and proven by the innovative research of few. Huang *et al.* showed that the combined strategy of using plants, PGPR, microbial inoculants, and land-farming has great potential to remediate large amounts of persistent organic contaminants from soil. Final analysis showed that out of a total of 16 PAH compounds ranging in size and recalcitrance, 80% were removed from soil. The total contaminated material that was removed during the research period was 95%. In addition and of great significance, was the removal of low levels of metals from the same soil. Approximately half of the known and accounted for hazardous metals were removed from the site. Although not the contaminants of interest and focus of analysis of this particular research, it is notable in that it shows even greater promise and viability for a MPPS strategy in soil environments with multiple mixed contaminants typical of most contaminated sites. In several studies, both in collaboration with Huang and separate, Greenburg *et al.* demonstrated in greenhouse and field trials that a MPPS strategy was superior to any of the conventional individual methods for removal of contaminants from soil. Steve Rock of the EPA and one of the leading experts in the field of applied phytoremediation, has proposed similar systems he refers to as Engineered Phytoremediation Units. Kirkwood in Manufactured Sites, highlights this concept through the lens of landscape architecture and gives reflection on the opportunity such systems have for the expansion and integration of design with site reclamation.

Also fundamental to a MPPS strategy is the necessity for continued expansion of it. Specific agronomic practices can be tailored to accommodate better contaminant removal and enhanced plant growth. In experiments performed by Olson et al. (2008), clipping (mowing) and fertilizer inputs of perennial ryegrass (*Lolium perenne*) and its affect on the removal of PAH-contaminants was tested. Findings indicated that *Lolium p.* significantly enhanced PAH dissipation. Additionally, it was determined that fertility inputs alone actually impeded processes of microbial influenced PAH removal (speculated to be caused by fertility inputs favoring non-degrading species), while clipping alone promoted an increase in populations of PAH-degrading species.

Combined application of both clipping and fertilization did show positive results, but only as a result of the influence clipping had on mitigating the negative effect of fertilization. Implications for landscape architecture and site design as a result of Olson *et al.*'s research combined with research done on N-fixing phytoremediators is clear; management practices can have a significant influence on remediation success and processes, and creates further opportunity for progressive exploration of dynamic planting design which incorporates both plant characteristics and subsequent management-input influenced spatial affects.

When using the MPPS framework with optimizations of each component described in this review, as well as specialized agronomic practices and amendments (such as earthworms in the land-farming phase), further efficiency and expediency can be made, offering an undeniable economic, experiential, and environmental advantage over conventional land decontamination strategies. In exploring how a MPPS strategy can be expanded upon, research from multiple disciplines can create a truly interdisciplinary collaboration of many fields of study and expertise. This opportunity not only broadens and nurtures an understanding of ecological site remediation, but also engages and synthesizes the ideas of many that would not have had the opportunity for integration otherwise. For landscape architects, this synthesis provides new direction for ideas of spatial thought and organization, and to evolve and clearly merge site decontamination with the expressive cultural urban landscape, planning, and processes of both landscape and socio-physical urban succession .

<u>Remediation as Continual Urban Ecosystem Process</u>

In order to understand the spatial and temporal framework for designing spaces with multiple values (social, environmental, economic) within an ecological remediation/succession system, it is essential to understand the basic mechanisms of ecological succession and accompanying processes. Specific to this particular design exploration, urban influences on 'natural' processes is of even greater importance for the development of conceptual spatial organization, ecological remediation systems, and management planning of parcel-scale sites and their relationship to neighborhood- and greater city-scale.

The summary begins with a brief discussion of fundamental ecological succession via Clements Theory, and continues with more contemporary considerations/theories of causes and mechanisms of succession, as well as the relevance of equilibrium/non-equilibrium theory as it pertains to urban ecosystems and spatially expressive land decontamination. Particular exploration of microbial succession in the urban soil environment, its influence on, and reaction to above-ground biota (plants, anthropogenic impacts, etc.) and successional processes, and the confluence of a multi-process phytoremediation system and its particular microbial evolution and behavior relative to transitional (contaminated to decontaminated) soil conditions are made. In light of the extreme complexity of synthesizing multiple elements within a unified design framework and the inherent site specificity of remediation strategies, the design discussion primarily serves to explain and identify pertinent relationships and considerations when approaching urban land reclamation using a MPPS/succession system. The concepts proposed are related to site conditions present at the Appleton Street parcel, and the study area as a whole in Holyoke, MA identified in the project scope and assessment section of this document. Conclusions regarding applicability using current brownfield regulatory and redevelopment tools as well as scalar unification of the anchor sites collective identified in the study area are made. In addition, ideas for adopting a more innovative overall citywide planning strategy complimentary to the proposed land decontamination/reclamation concepts attempt to merge the science and art of remediation/succession design with the socio-economics of policy.

Frederick Clements' theory of ecological succession was proposed in 1916 as an attempt to understand the forces contributing to landscape and ecosystem development. In succession where no soil is initially present on the landscape such as volcanic formations, glacial till, earthquakes, and climatically influenced landscape occurrences (i.e. a body of water draining and/or drying) succession is characterized as 'primary'. Primary succession is typical of 'unstable' (unpredictable) environments and is predominately colonized by 'opportunistic' species known in r/K selection theory as r-selection species. R-selected, or r-strategist species, often exploit non-competitive environments, produce numerous offspring, and have high mortality rates. Organisms typically defined as r-strategists range from bacteria to herbaceous vegetation, insects and small mammals. As r-strategists proliferate and an increase in energy as a result of photosynthetic capture enables greater biodiversity, species reach a 'climax community' in which K-strategists begin to exploit landscape resources for survival and proliferation. In secondary succession where soil is present, K-strategists are different in that they demand greater resources, have greater competition, have fewer offspring, and low mortality rates. Species characterizing K-strategists can include trees and other woody plant species, various soil microflora, and animals ranging from birds to humans. K-strategists are thought to create/occupy 'stable' (predictable) environments because resource competition typically creates a relatively constant and maximized population (i.e. site carrying capacity), often referred to as reaching the 'potential vegetation' of a site. This 'potential vegetation' is hugely influenced by local climate, and is often much less species diverse in community structure than that of primary succession species which maximize biodiversity prior to secondary species proliferation. In contemporary ecology, the theory of reaching a 'climax community', or equilibrium, has been abandoned by many in favor of a 'non-equilibrium' theory which proposes disturbance as a fundamental element of ecosystems. This differs dramatically in that equilibrium ecology offers a beginning and an end, while non-equilibrium ecology suggests disturbance as a critical element in ecosystem process and denies a beginning or an end; simply, an ebb and flow of energy inputs and outputs, stochastic (random) processes, and the role of contingency in community development. Thoughts on succession are further clarified using Steward Pickett's (1987) exploration for defining it, in which he proposes three hierarchal levels of causes and mechanisms. The **highest hierarchal level** involves general causes of succession that include: 1. open sites that become available, 2. species that are differentially available to an open site, and 3. species characterizing differential behavior at the site. The **intermediate hierarchal level** considers ecological processes and relationships relative to the general causes of succession described in the highest level. In regards to *site availability*, the general cause is disturbance. The second, *differential species availability*, is a function of the processes of dispersal and the dynamics of the propagule pool. The third, *differential species performance* (behavior), is broken down into relations of the following: resource availability, ecophysiology (the interrelationships between the physiology of organisms and their environment), life history strategy, stochastic environmental stress through the sere (*sere* is a series of ecological communities formed in ecological succession), competition, allelopathy (the suppression of growth of one plant species by another due to the release of toxic substances), and herbivory and predation. Understanding the intermediate level phenomena and processes by specific examinations of factors that determine outcomes and impacts in a particular succession defines the lowest, most detailed level of hierarchy. It is with exploring the **lowest hierarchal level** that assessment and modeling can be made, informing subsequent predictions regarding the path of succession at a given site.

Although extremely valuable in most contexts of ecosystem succession valuation, Pickett's proposed hierarchal tool is complicated in a post-industrial urban environment where disturbance is nearly constant (in the sense of land being idle and unable to be reclaimed as a result of fiscal constraints for redevelopment) and characteristic of much different phenomena (anthropogenic influences), processes, scales, and environmental stressors (i.e. elevated temperatures, unnatural hydrological processes and patterns, little or absent indigenous plant communities, compacted fill soils, etc.). Additionally, energy flows (namely anthropogenic) in and out of post-industrial cities are intermittent and less predictable compared to active, productive, and established urban environments. This being said, all cities characterize a much different and complex ecological phenomena. Although significant in relating design proposals of this project with urban design, planning and post-industrial reinvention, in depth discussion of ecological/resilient urbanism is far beyond the scope of this particular exploration and will be assumed as such in further discussion.

As the section title states, this is a discussion of remediation and its communion with urban ecosystem processes. In the urban ecosystem, processes are perpetually interacting with and influenced by human behavior. This in mind, the role of succession can become either literal or metaphorical. Keeping in mind as well that non-equilibrium ecosystem succession is a dynamic process in which a climax state is nonexistent, site remediation and its integration with the socio-cultural milieu therefore can become a fusion of literal successional processes such as plant community development, and metaphorical successional processes in which human community development behaves and is interpreted within a similar hierarchal tool. Site redevelopment then becomes an opportunity to align currently fragmented components of urban planning and design, and exploit contaminated land not simply as open space in need of something or anything, but rather *a site of disturbance that conveys a new approach* for determining the most appropriate (in terms of both humans and/or ecosystem services), yet temporary land use. Brownfields can be reinterpreted as effective genesis sites for adaptive municipal planning strategies in multiple scales and contexts. The model of succession in turn becomes both literal; such as in the case of MPPS systems laying a groundwork for biological successional processes to emerge, and metaphorical; in which land use programming is determined based on emergent human behavior resulting from interaction(s) with site remediation processes (MPPS), community goals, and spatial patterns. The balance between the fusion of literal and metaphorical succession is deterministic only in the sense of establishing community goals of renewal and reinvention, and is subsequently weighed by the emergent dominance of one-or-the-other, or both.

Literature Review Conclusions

The literature review reveals the extreme complexity, site-specificity, and variability of phytoremediation and associated processes. Opportunities and more importantly limitations of phytoremediation alone, highlights the need for an integrated ecological remediation approach. The implications for expressive design using a multi-process approach that at its core relies exclusively on plant capacity to support decontamination processes, is completely aligned with the creative and professional skills of landscape architecture. Emergent in process design are new methods, spatial opportunities, temporal dynamics, and implementation and management practices. The necessity for including a landscape architect in the first phases of planning, designing, and implementing brownfield remediation is vital. Together with all other invested parties, the reclamation of urban land becomes synthesized with municipal goals not only for the site itself, but as well the neighborhood, community and city as a whole.

The review very much reveals the science of remediation in hopes of conveying the importance of a landscape architect understanding the decontamination processes. Only with this understanding can the landscape architect begin to offer unique, human solutions for site remediation. The following design discussion and conceptual design model will attempt to spatially illustrate how the processes of ecological remediation, natural succession, urban context, and community goals can all be synthesized and aligned to become a unified urban healing initiative, replicable in any urban context and site conditions.

Design Discussion

Introduction

The brownfield site located on Appleton St. which lies between the 1st- and 2nd-level canals, and adjacent to Heritage State Park is a municipal priority for redevelopment. The Canal Walk, already in construction and directly adjacent to the site, seeks to unify and connect the growing artistic community with existing industrial activities (though few) in and around the immediate area. The 'Arts and Industry District' as it's been coined, is being proposed as a social hub of cultural activity in the central downtown, and defines the municipal goals of renewal and reinvention for this area of the city. Potential plans for redevelopment of the Appleton parcel include an urban park, a parking lot, or a new industrial/commercial facility to be built by a private developer. The disconnection between established goals for the district and parcel redevelopment is clear in that filling the space with a parking lot, or a new most likely architecturally challenged commercial/industrial building, would have little nurturing capacity for realizing the stated goals, and as well deter from the rugged charm of the turn-of-the-century mill buildings, canal walk, mill race, and canal itself.

Reinvention of the site as an urban park is aligned with the stated goals, but has vulnerability in that without supportive activities in and adjacent to it, most likely would remain a vacant, essentially dormant space. The MPPS/succession system has marvelous opportunity for multi-scalar and multi-contextual success at the Appleton parcel and Canal Walk corridor, and could genuinely provide a symbol of progressive renewal in the city. Additionally, succession as a metaphor (in this particular case) would enable a migration of similar initiatives to begin 'fingering' out from the site (similar to that of plant community succession in disturbed rural environments). In understanding the fusion 'ratio' of literal and metaphoric succession for the Appleton parcel and connecting corridor, the goals for the district allow for clarity of the primary design consideration. Based on the desired outcome of creating a social and cultural hub, *metaphoric succession promotes human behavior and interaction with the dynamic MPPS processes* and could become an artistic and industrial anchor for further enhancement and renovation of sites connected by the Canal Walk. The traditional urban park would then become not only a collection of 'natural' and human spaces, but as well a dynamic and extending remediation venue for interpretation and engagement by the artistic and greater community. The role of the landscape architect is to unify scientific efficacy (decontamination) with spatial expression, organization, and development as a way to promote the dynamic inclusion of other creative contributors. This collaborative would promote the health and wellness of both the environment and participants, enable economic growth as a result of increased visitation and small business/studio occupancy adjacent to the site and Canal Walk (current mill buildings are mostly vacant and seemingly abandoned), and clearly convey visually and culturally the Arts and Industry District (wayfinding). Although metaphoric succession is the primary design consideration for the decontamination and reactivation of the Appleton parcel and corridor using a MPPS/succession framework, biological successional processes are inherently complimentary for promoting sustainable built environments and integrating artistic expression with the media of landscape architecture. As mentioned, the framework for implementing and integrating decontamination and expressive landscape experiences is the role of the landscape architect. The physical manifestation of this unity will be discussed in the following section, and explicitly highlights the spatial transition from a contaminated site using a MPPS strategy to a cleaned site (the science of effective decontamination and subsequent design implications) as well as spatial implications for active use while in remediation. In addition, discussion will incorporate the creation of artistic commissions and allowance for guerrilla art (i.e. non-commissioned art such as graffiti) in concert with remediation processes that both enhance the experience of migrating to, entering, and resting in the space , as well as acknowledge the communion of remediation with ecosystem processes and artistic expression.

Designing Multi-Process Phytoremediation System/Succession Processes

Design considerations for the Appleton parcel include the need for remediation of PAH compounds and low levels of the heavy metal nickel (Ni) at various elevations (1'-9') in the soil, a contextual and physical acknowledgement aligned with the desired municipal goals of the Arts and Industry District and Canal Walk, and land use activation while in remediation. Additional design considerations include the need to preserve existing natural and cultural resources located on and adjacent to the site. The design concept integrates contemporary site design with the processes of a MPPS/succession system. To do this, phased out implementation is proposed that visually makes clear the decontamination processes and engages visitors and the artistic community as inclusive participants in local land reclamation.

Design explanation begins with discussion of the northwest side of the parcel adjacent to both the 1st-level canal and Canal Walk. As indicated in the assessment, hazardous levels of PAH compounds currently buried below grade are located at varying elevations in and around the interior volume of the remaining building foundation (NW side), measured approximately 50′ due SW and 100′ due SE from the NW corner of the buried foundation structure below the existing grade spot elevation of ~ 98′ (approximations are based on limitations of available project data).

The use of a MPPS strategy begins with the removal of contaminated soil from spot elevation 98′ located at the NW corner identified as the corner of the existing buried foundation. Excavation depth will not exceed 4 feet, shot from the identified spot elevation and be measured in area approximately 45′ SW and 90′ SE from the defined spot elevation (true bearings are unavailable due to limitations of data acquisition). Due to the descending existing grade of the site in the defined excavation area (98′ to 95′ due SE), actual depth of material excavation will decrease as a result of descending existing grade, keeping in mind excavation depth is based off of the defined spot elevation of 98′. This compliments the concentration levels and known depth of contaminants onsite. The excavated material becomes the land-farming media characteristic of the initial phase of a MPPS. The excavated material is then thoroughly homogenized onsite before reallocation. This not only promotes contaminant uniformity, but as well aerates and exposes all soil material to both oxidation and light. Although energy intensive and potentially hazardous to construction crews, safe harvest and handling of contaminated media during onsite preparatory treatment is still preferable over harvest and transfer to a distant landfill. Additionally, the costs attributed to onsite treatment are dramatically lower than that of disposal at an appropriate landfill facility. Also, as mentioned in the review, it is ethically questionable to acknowledge distant, untreated geographic relocation as effective remediation practice.

Connecting the Canal Walk with Remediation Design

The experience begins at the northern gateway of the 1st-Phase canal walk located at the intersection of Dwight Street and proposed Canal Walk corridor. Staggered steel columns and cable-stays support an elevated, suspended, variable frequency sinusoidal arced 2' - 3' wide, 1' deep planter undulating 14' overhead. The structure migrates through the corridor, vertically and horizontally fragmenting and dissolving within the contamination origin (Appleton parcel). The 'skyREM' structure serves multiple roles. As an elevated remediation structure, the skyREM contains the homogenized soil harvested from the Appleton parcel. MPPS mechanisms are activated immediately during the harvest, mixing, and transfer processes. The skyREM structural design consists of multiple layers similar to existing green roof systems; with a media layer (contaminated soil), aeration and water retention layer that would both retain and store water as well as increase oxygen availability for enhanced microbial action, an impermeable membrane to preserve the structural integrity of the elevated steel and concrete suspension structure, and the physical structure itself. As a visual representation of decontamination, (L)ight (E)mitting (D)iodes placed consistently along the underside of the structure would illuminate the corridor, canal, and reflective surfaces interacting with the skyREM (i.e. commissioned art pieces integrated into the support columns and nodal spaces). The LED's would be dynamic in color, ranging from red (contaminated), purple (less contaminated), and blue (clean). The light control is fully automated and reacts to contaminant assessment remote data inputs (i.e. a lab).

Following the land-farming and microbial inoculation phases of the MPPS, PGPR-enhanced indigenous herbaceous plant material is installed. A mix of indigenous species supportive of both MPPS function and 'native' aesthetic are installed in dense massing in individual skyREM partitions. Species recommended for use are Switchgrass (*Panicum virgatum*), Wild Carrot (*Daucus carota*), Blue Fescue (*Festuca ovinia var. glauca*) and Goldenrod (*Solidago canadensis*). To present opportunity for plant/contaminant evaluation, partitioned segments delineated by arc segments of the skyREM structure are planted as single-species massing, dual-species massing, and total mix massing. Remediation timeframes and efficacy are clearly defined and monitored enabling subsequent re-tooling of skyREM segment species.

The curvilinear form of the skyREM is such that it creates opportunity for planting and resting nodes at corridor grade that react to the elevated formal arcs of remediation overhead. The geomorphic nodes extend in and out of the corridor creating a wonderful contrast with the organic migration of the skyREM through the linear geo-enhanced urban space. The nodes protrude both; out into the canal providing waterfront prospects, and in towards the existing architecture creating an organic migration of both people and structure in a formal linear corridor. Plantings in the nodes consists of designed, but informal combinations of indigenous species characteristic of late succession northern forest communities such as Sugar Maple (*Acer saccharum*), Witchazel (*Hamamelis virginiana*), Mountain Laurel (*Kalmia latifolia*), Mapleleaf Viburnum (*Viburnum acerfolium*), Hobblebush (*Viburnum lantanoides*), Striped Maple (*Acer pensylvanicum*), Yellow Birch (*Betula alleghaniensis*), the groundcovers Hay-Scented Fern (*Dennstaedtia punctilobula*), Wintergreen (*Gaultheria procumbens*), and Bunchberry (*Cornus canadensis*), and herbaceous plants such as Foamflower (*Tiarella cordifolia*), Solomons Seal (*Polygonatum commutatum*), and Jack-in-the-Pulpit (*Arisaema triphyllum*).

The informal indigenous planting combinations occupying formal geomorphic groundspace that reacts to the elevated curvilinear skyREM structure, evokes a sense of formal informality and proposes a vertical display of biological succession in which the disturbed and treated landscape, represented by the skyREM structure, meanders through the canopies of late forest communities, acknowledging the non-equilibrium nature of natural community development. In terms of metaphoric succession; the skyREM structure suggesting urban context, and accompanying reactionary informal planting spaces suggestive of natural context; provides a series of artistic intervention zones in which the social and cultural succession of the District can begin to evolve and morph into a self-supportive artistic community. Creative interventions in a variety of media would manifest as a continued dialogue considering the urban/nature contrast by incorporating industrial art into the informal spaces of 'nature', and art more evocative of nature (i.e. Goldsworthy, Dougherty, etc.) would be fused with the visually urban and engineered cable stay structures of the skyREM; again evoking a sharp contrast and fusion of contexts. Enabling multiple contexts of artistic expression in the spaces creates a venue supportive of multiple artistic expressions, unbiased to one or the other, promoting greater creative diversity in the District.

In addition to the ground-plane experience, the skyREM corridor promotes multi-horizontality. The existing architecture of the revitalized adjacent industrial buildings provides overhead views of the skyREM. Appropriate architectural programming on higher floors such as studio and/or living space, retail eateries, etc. on the canal walk side would create a wonderful visual experience for occupants to interpret the corridor in an entirely different and elevated way. *The skyREM structure becomes an abstract urban window box*. The planting design of the skyREM segments becomes visual and expressive while still functioning as cleansing infrastructure. Looking down on the corridor, the contrast of the skyREM finely textured ethereal-colored plantings as it meanders through the bold colors and coarse textures of the forest canopy nodes and as a collective aesthetic engaging the canal, would offer an entirely unique visual experience. Similar to the ground-plane experience of vertical biological succession, the elevated experience creates a clear connection of human engagement in urban ecosystem processes, yet from a vantage point often unavailable. Also inherent to the skyREM corridor is the daily evolution of the place. The rich botanical/architectural fusion during the daylight hour projects new and mutant shadow experiences; while in the evening hours, the multi-colored glow of remediation progress highlights both the science and the artistic inclusion of the site. Art pieces on display could then exploit the play of light in both day and night, further enhancing the experience of visitors migrating through the spaces and allow for, and promote expanded daily commerce in and around the site. Upon the approach to Appleton Remediation Park, the final arc of the skyREM reaching over the canal inspires the expansion of park spaces into the existing canal. Open geomorphic spaces provide wonderful water views looking both north and south along the canal. Additionally, the existing mill race located on the Appleton parcel is highlighted by calling attention to the authentic arched mill race entry still functioning on the canal. The significance of this is both historic and ecological. The history of the site is acknowledged by simply pointing it out with complimentary spatial arrangement. The ecological significance speaks of the ebb and flow of natural systems. As mentioned, the mill race is presently more an urban wetland than a functional industrial water chute. To emphasize the ecology and inherent change of the place, the interior aquatic spaces are designed to promote continued wetland development by arranging the built geomorphic forms (and spaces) to promote proper hydro-period, sediment displacement, and subsequent emergent hydrophytic vegetation. Additionally, the wetland would serve as a secondary filtration pond for stormwater runoff from the park. The pathway of design development is truly unique in which ecological remediation informs structural forms, forms inspire spaces, and spaces provide opportunities for green infrastructure and enhanced urban ecological services.

The skyREM connection and Appleton Remediation Park

The skyREM corridor in and of itself provides a very powerful urban landscape experience, but still in its simplest terms, functions only within the urban network as a connector of places in and adjacent to the Arts and Industry District and to fulfill MPPS processes while urban land is in active use. This distillation highlights the immense importance of the Appleton parcel as an anchor site for the unification of sites both in and around the District, as well as outlying future connections to other city sites and neighborhoods demanding renewal and reinvention initiatives. The Appleton parcel is also of critical importance in that it provides the seed from which the Canal Walk can become more than a paved area of little engagement with urban and ecological processes. This in mind, the design concept for Appleton acknowledges the remediation goals of the site, the need for powerful and pronounced gateways in from the skyREM corridor (aka Canal Walk) and other entry points into the site, the potential for future expansion and unification with the 2nd-level canal to the southeast, and the necessity for comfortable and spacious areas of rest and contemplation not currently available on the east side of the 1st-level canal.

The gateway to the park via the skyREM corridor offers the greatest opportunity for establishing harmony between the human migratory experience of remediation and the restful, contemplative, and interactive remediation spaces of the park. The varying and increased frequency of the skyREM sinusoidal arcs decreases as one approaches the park, encouraging a more passive engagement with the spaces to come then experienced on the ecological, social, and cultural thrill ride characterizing the skyREM corridor migration. Though the sensory engagement is purposefully stifled, the continuity of spaces, form, physical structure, processes, and purpose is still very much projected as, and attributed to the skyREM experience as one enters the park. The distinguishing element of entry is the skyREM traveling completely overhead into the park where the structure steps down and vertically diffuses (in a horizontal way) into the planted meadow area of the site. The entering skyREM arc travels parallel and proportional, yet offset to the arc of phytoremediation trees and adjacent formal arced path leading to the greater common areas of the site. The skyREM at its terminus spatially embraces the park clearly defining entry points and inclusion of the canal walk with the park. It is with the vertical dissolve of the skyREM that elements of it begin to reappear as one explores the spaces within the park.

The immediate area off of the skyREM corridor as one enters is defined by two arced collections of six Quaking Aspens (*Populus tremuloides*) spaced 10′ apart along the arc-centerline that serve as the primary phytoremediators in the MPPS/succession over the contaminated area of the site (spatially located and described in the beginning of the design discussion section) . The initial MPPS processes; land farming, microbial inoculation, and PGPR inoculation of Aspen roots (in a controlled greenhouse environment) is implemented following initial harvest of soil for transfer to the skyREM structure. The remaining soil (~ 5′ to building foundation) following the harvest, is periodically tilled and aerated so as to increase volatilization and photo-oxidation. Subsequent microbial inoculation is performed (using harvested indigenous species gathered during initial harvest and lab-cultured for reintroduction) and analyzed after a specified period for population densities and degradation pathways/products. When sufficient contaminant degradation of low-weight PAH's is achieved, planting of inoculated *Populus sp.* is implemented to further support large-ring PAH degradation. Immediately following successful rooting and establishment (determined by height, caliper, and plant health) of the *Populus sp.*, customized light-weight aluminum alloy grates are placed on steel beams attached to previously installed foundation walls (TOW=SpE.98′) located on the perimeter of the initial soil harvest area. The 'floating' floor grates allow for visitor separation from contaminated soil media below and spatial exploration of the contaminant-inspired planting layout of the Aspens. In the evening hours, the open space between the treated soil and floating floor becomes illuminated much like that of the skyREM structure. The representational nocturnal glow of both the below grade remediation processes and overhead processes truly unifies the horizontal planes of cleansing and makes legible the origin of contamination and treatment approach (in literal and figurative terms). As one travels through the intimate and botanically enclosed spaces of the decontamination zone, a pronounced sense of refuge evokes and transcends a space of intensive disturbance and healing, culminating as one travels down-grade into the dynamic geomorphic spaces of the 'hard' plaza. The sense of spatial relief when entering the plaza space further exaggerates the intensity of remediation, evocative of hope and optimism. The plaza consists of two large open spaces; one hard, and one soft.

The 'hard' space is indicative of intellectual exchange, artistic collaboration and exhibition, and further connection with succession communities. The space is defined by a collection of geomorphic spaces that not only merge and unify with one another evoking a greater spatial experience, but also identify 'rooms' that convey spatial separation. Plant community succession is projected using a dense vegetative edge and screen on the street side beginning as one passes through, and exits the remediation zone, with dense meadow plantings further acknowledging the transition of contaminated land using both the model of succession and the vertical dissolve of the skyREM structure. Moving east and into the geo-plaza space, the street-side screen evolves into a plant community typifying species of New England forest communities, continuing east defining the 2nd-level canal edge and eastern gateway into the park. The forest community design combined with geomorphic forms and spaces of the hard plaza, maintains a conversation with the skyREM corridor nodes, further unifying the experience of travelling to and coming to rest in the park. The perimeter edges of the geomorphic plaza spaces provide unique sitting areas suggesting observation points and refuge from afternoon sun. Sculptural art would compliment these resting areas providing additional exhibition space for local artists. The hard plaza area is further enhanced and spatially manipulated by a dynamic, fun, and relevant park accessory; mobile tree units. The 'tree-trains' consist of a single medium-sized deciduous tree planted in a 12′ x 10′ x 3′ specially designed container that houses working recycled train wheels and travels along reclaimed track installed within the hardscape of the urban plaza. Using fundamental physics and proper gear ratio design, the tree-trains allow visitors the opportunity to engage in creating their own spatial experience by turning a wheel, resulting in the transfer of their energy (potential energy) into movement (kinetic energy). The tree-train not only visually and spatially alters the site in multiple temporal scales, but as well recognizes the heritage of Holyoke's extensive rail system, enabling visitors to become active participants in not only the parks day-today dynamic, but also the abstract reinterpretation of history in Holyoke. Additionally, the arced layout of the rail lines continues the harmony of merging geomorphic elements with organic curvilinear forms experienced along the skyREM corridor and Remediation Park gateway. The tree-trains also speak of the dynamic nature of plant community succession by emphasizing movement and change in and around the established planting areas. At first glance, the tree-trains appear to be a static, immobile plant element within the greater collection. When mobilized via visitor inclusion and engagement, the 'forest' seemingly breaks apart becoming reorganized and reshaped. This abstract representation of succession considers the impact of humans on their environment, the reactive energy obliged for ecological and cultural restoration, and the dynamic nature of the landscape with or without human inclusion.

The eastern gateway (2nd-level canal) to the park consists of long, gentle, 18"-wide (tread) steps serving both to join the existing elevation of the east side and 2nd-level canal with the plaza elevation, and provide informal seating overlooking the 2nd-level canal. The existing waterwheel foundation structure not only provides opportunity for a dominant gateway feature, but also serves as a physical separation between the entry steps and accessibility entrance (also serves as a central axis connecting one side of the park to the other, and edge separating the hard space from the soft) located between and adjacent to the existing outbuilding structure and water wheel structure. The waterwheel structure would be rehabilitated and a new, efficient hydropower wheel installed. The functioning hydro-electric water wheel would support the energy needs for the park and immediate outlying facilities, as well as continue and display the hydro-electric heritage of the city. Small informal sitting areas that are an extension of the east entry steps wrap around the structure allowing for hypnotic observation of moving water and machine. The space transitions into the geo-plaza and 'soft' plaza using the plant community model to again engage succession as an expressive landscape. The plantings characterizing the northern edge of the geo-plaza include mesic community species such as White Pine (*Pinus strobes*), Gray Birch (*Betula lenta*), Steeplebush (*Spirea tomentosa*), Sweetfern (*Comptonia peregrina)*, and Northern Bayberry (*Myrica pennsylvanica*). The placement of transitional species; those that proliferate between the meadow stage and mature forest stage such as small deciduous trees, evergreen species, and woody shrubs highlights not only the visually absent stage within the park plant succession collective, but as well characterizes and exaggerates the transitional space in which they occupy; that being the space between the hard plaza (geo) and soft plaza.

The expression of the hard plaza proposes a connection with the remediation/succession processes in a manner typifying the traditional urban plaza space, albeit in a unique and process-based way. The purpose of the soft plaza is to invite relaxation, passive and active recreation, and viewing of performance art. The open green extends from the skyREM corridor to the existing outbuilding located at the eastern side of the park. The green is offset 5’ from the existing mill race structure allowing for a perimeter walk and overlook into the mill race, now urban wetland. The space is elegantly simple, consisting of a level turf area enclosed by a strong tree-line along the mill race corridor and accessible central axis corridor of the park. A solitary boulder midway across the green is dug in to appear as an exposed bedrock surface and serves as informal seating, and visual cue acknowledging a gentle down-slope to the existing outbuilding and performance area. Also indicative of slope change is an arced strip of pavers that serve as both a decorative and repeated design element. The green is meant to promote passive and active recreation, relaxation, and comfort. It is a space of urban refuge, Frisbees, and quiet midday napping.

The proposed framework and conceptual design for the skyREM corridor – Appleton Remediation Park attempts to unite multiple goals. The use of a MPPS/succession model clearly illustrates the possibilities for ecological remediation success and informs new creative interpretations of space, planting design, succession as both a literal and metaphoric design model, and land activation while in decontamination. In addition, the skyREM – Remediation Park depicts land reclamation not as a nuisance, but rather an opportunity for achieving municipal goals in ways not possible without the need for cleansing infrastructure and processes. As stated in the review conclusions of MPPS, the need for continued expansion and improved efficacy is necessary. Sites such as the

Appleton parcel, provide a unique platform for further refinement and clarity into how all processes nested in the system work as individuals, and collectively. The marvelous potential of MPPS expansion involves site specificity, both with the contaminants and context. The design solutions and recommended processes proposed for the Appleton and corridor sites are a direct result of the contaminant types and location (location being multi-scalar: in the city, in the District, on the site, depth in the soil, etc.), and municipal and community vision for the place. A site with different municipal programming in mind; different contaminants types, concentrations, and locales; and design considerations working within a succession model, will all manifest differently and provide new opportunities for research and knowledge; both scientific and in design. The skyREM-Remediation Park in this context takes on a much more important role: to catalyze progress in multiple scales and contexts, from the artist struggling to gain exposure, to a scientist seeking a conclusion, a family looking for a Sunday afternoon activity, and a city desperate to recover.

Conclusions

Though a key site and the main focus of this project, the Appleton St. parcel is only one many brownfield sites located in Holyoke. Others include two former industrial sites along the Connecticut River. Brief discussion of these, though limited, will emphasize the MPPS/succession concept in terms of design consideration, namely literal or metaphorical succession.

Considering the two former industrial sites located along the CT. River it is rather intuitive to consider these opportunistic for MPPS/succession in literal/biological terms. Both sites; the former Norman Paper Co. site and the dilapidated former Hallmark Van Lines site offer great potential for anchoring restoration initiatives along the river. The fusion ratio, though primarily literal, would also encourage metaphoric succession in the sense of education and commerce. Both sites offer potential for reinvention as environmental learning institutions and could establish methodologies for further expansion of the MPPS/succession strategy (as mentioned in the conclusions of the MPPS discussion in the review). In addition, new green industrial ventures could manifest in response to an established research and development platform, and enable employment and educational opportunities in close proximity of residents living in the currently impoverished and environmentally unjust neighborhood of South Holyoke. The Hallmark site has marvelous potential to be re-imagined as an environmental interpretation center for both youth and adults alike to learn about the urban ecosystem they are a part of. The currently dilapidated structure appears as if a relic of the past that simply one day stopped. Sitting directly adjacent to the falls of the collective city canal system, the Connecticut River, and emergent wetlands taking over formerly active canal sections, the Hallmark site is the spatial anchor for the city – river connection.

Additionally, the proposed Connecticut River Greenway would intersect the site, allowing for regional and state connections.

The site is heavily contaminated with various heavy metals, organic contaminants, and fly ash. Unlike the Appleton parcel, progress in redevelopment is slow. The site offers wonderful opportunities for using the MPPS/succession framework for both decontamination and new architectural typologies to emerge out of the reuse and rehabilitation of the ruins. Much like the skyREM, the site offers great potential for new integrated structures, contextual sensitivity, decontamination, and active usage in remediation if approached using a MPPS strategy. Although time does not allow for in depth design exploration of this site for this project, the city should seriously consider the possibilities, based on concepts proposed for the Appleton site, for implementing ecological remediation strategies with site design at the Hallmark site.

Final Thoughts

The complexity of this exploration in the beginning was vastly under-estimated. The multi-disciplinary nature of the subject complicated intellectual connections and subsequent design considerations. As a designer, juggling the science of multiple components all of which involve excessive intricacies, made it truly difficult to unite design with effective environmental restoration. It is no surprise that exploration by the design professions into synthesizing ecological remediation with site design is limited and vague in many ways. That being said, the ideas proposed reflect at the very least a collection of relationships and considerations helpful when embarking on a journey of combined artistic expression and remedial design. Above all other design professions; engineering, architecture, etc., landscape architects possess an inherent understanding of multiple disciplines allowing for greater understanding and impact when considering the design of ecological remediation systems. Especially relevant is the primary consideration that dominates the landscape architect's design intentions: people. The acknowledgement of people and the spaces they occupy is the powerful remedial component that present day environmental restoration/engineering firms do not consider within the scope of a project solution. Typically the solution consists of a soil boring that a lab test identifies as contaminant negligible. While this does consider the biological health and welfare of people in and around the area of contamination and a decrease or removal of contaminants does benefit the safety of a community, it does not acknowledge the fundamental essence of humanity: imagination and emotional connections. It is imagination that promotes human interaction, intellectual exchange, personal enrichment, and societal progress. In the post-industrial urban realm, imagination is the guiding force for recovery and reinvention. The landscape architect's role is to bring the collective imagination together in a space that evolves through engagement and interaction to become a place. Emotional connections to a place are fundamental to the human condition. To reclaim a place only with the intent of creating a biological solution, denies the potential and opportunity for the resurrection and/or reinvention of a place. It simply maintains as a space, albeit one that wont negatively affect an occupants' biology and physiology, but still fundamentally a space with human deficit. The judgment of successful site remediation in this context should be seriously questioned. Is remediation only about physical health in the sense of providing environments that won't kill you? Is it only about economic recovery in which the reclaiming of a site provides municipal tax dollars and/or a potential business development venue? Is it only about providing ecological value? These questions or a combination of them currently informs the most suited remediation strategy. A more progressive and compounded question could be: Will it be a place that emotionally engages me? Or, can it be place I recall and long for when I'm away? The essence of place-based questions for determining suitable remediation strategies acknowledges all of the above space-based questions, yet under an umbrella of emotional engagement. Of course in the current regulatory framework, end land-use is essential for determining level of site decontamination which in turn typically proposes the remediation strategy based on minimizing monetary costs. Even within this context, the idea of site decontamination solutions recognizing the reinvention of place is significant. Regardless of end land use; whether it be a park, building, or other; they all offer opportunity for the unification of design and decontamination. The skyREM proposed for the Appleton site illustrates a concept that could be applied in multiple ways. If a site was to be redeveloped primarily with a newly constructed building, the engineering of the building could be such that would support ecological remediation processes on the roof. This, much like the skyREM, would fuse remediation with site design in a way that not only acknowledges site decontamination, but as well exploits it for future (after decontamination) engagement by people and wildlife alike, all the while fundamentally maintaining a connection with the layered history of the site.

The fundamental knowledge gained from this design exploration in the end identifies three main ideas:

1.) Site remediation is an opportunity for reimagining its very definition. Reclaiming urban land does not have to be a nuisance to redevelopment. Remediation becomes not only a solution for cleaning junk, but a chance to create a new urban experience.

2.) Site redevelopment must go beyond a vision of 'space'-reclamation, and consider moreso the opportunity for reinvention of a 'place'.

3.) Multi-process remediation and integrated ecological systems provides a tool for achieving multiple goals in multiple contexts with multiple outcomes when applied to site remediation.

References

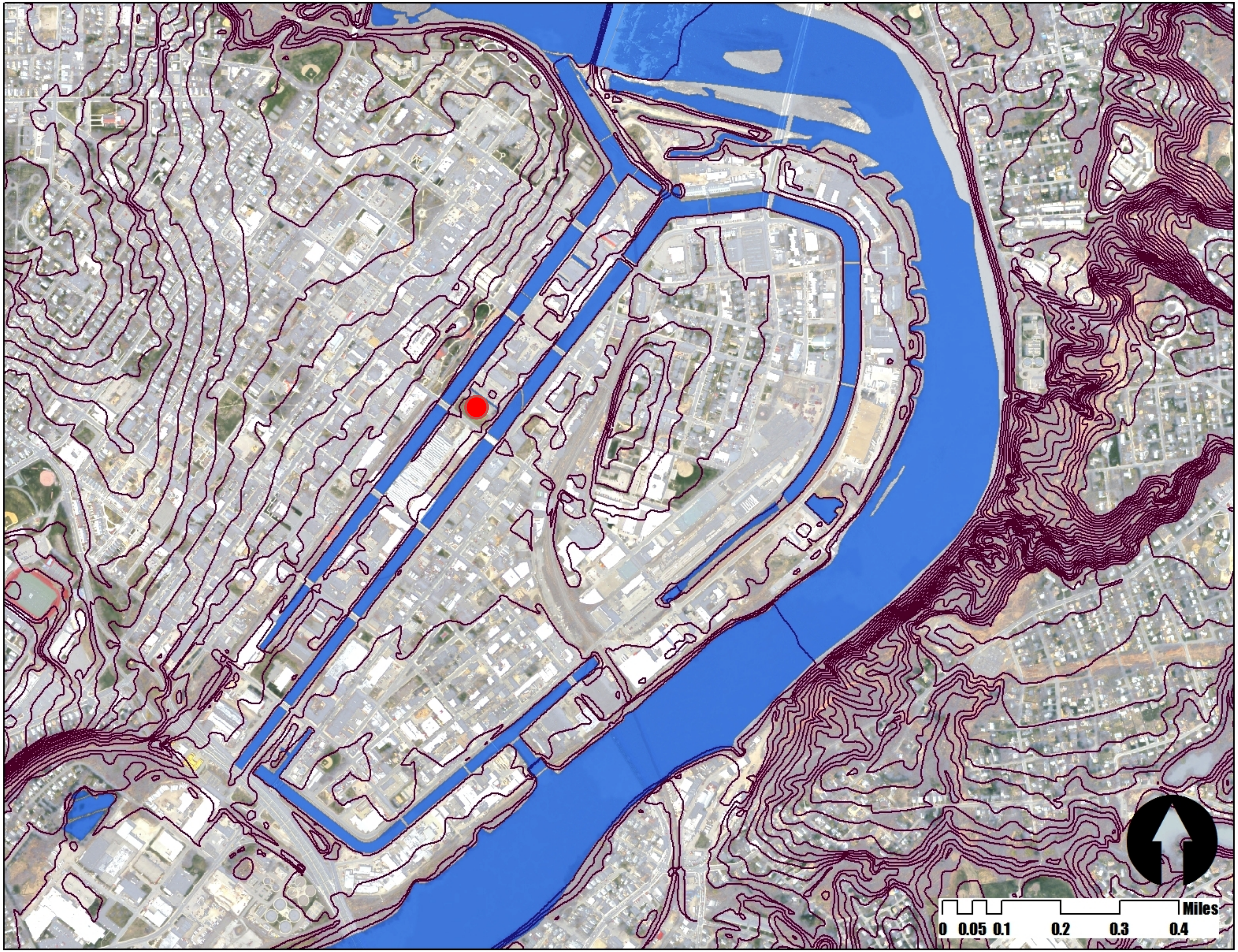
Appendix

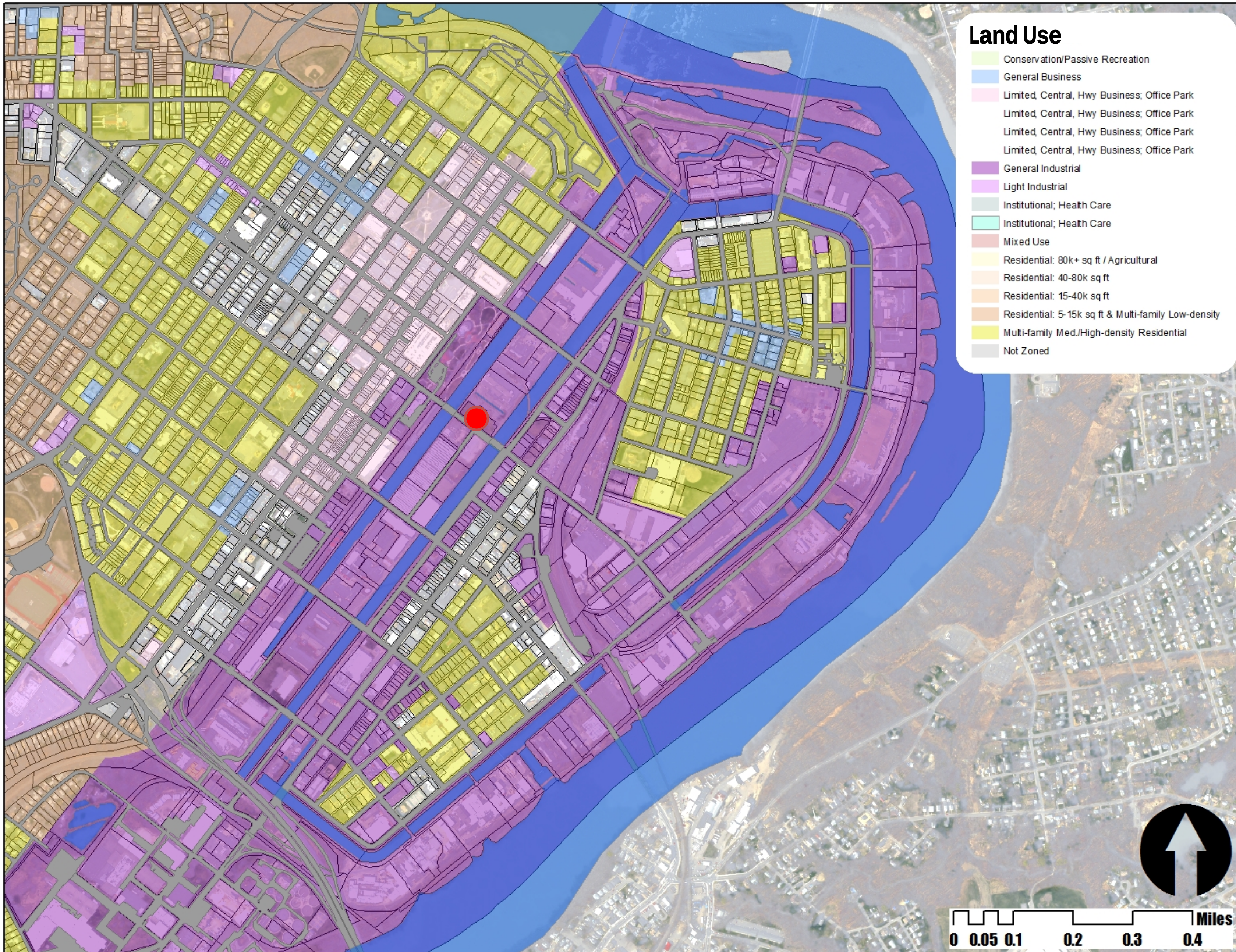
Appendix I – Assessment Maps & Contaminant Analysis

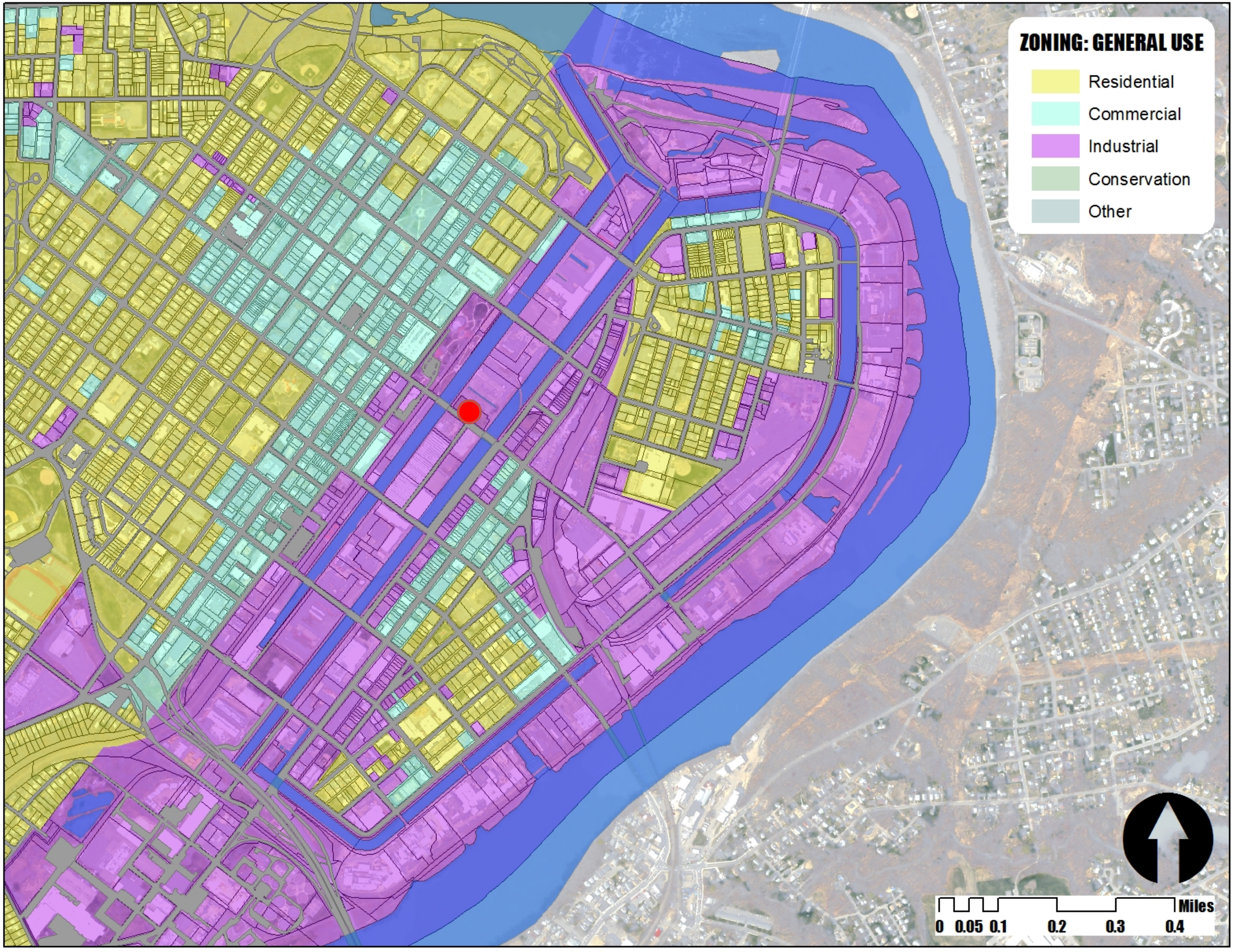
Appendix II – Site Photos

Appendix III – Design Documents

Contour interval = ten feet




Land Use
Conservation/Passive Recreation
General Business
Limited, Central, Hwy Business; Office Park
Limited, Central, Hwy Business; Office Park
Limited, Central, Hwy Business; Office Park
Limited, Central, Hwy Business; Office Park
General Industrial
Light Industrial
Institutional; Health Care
Institutional; Health Care
Mixed Use
Residential: 80k+ sq ft / Agricultural
Residential: 40-80k sq ft
Residential: 15-40k sq ft
Residential: 5-15k sq ft & Multi-family Low-density
Multi-family Med./High-density Residential
Not Zoned
0 0.05 0.1 0.2 0.3 0.4
Miles



ZONING: GENERAL USE
Residential
Commercial
Industrial
Conservation
Other
0 0.05 0.1 0.2 0.3 0.4
Miles

Walk time from site is illustrated by blue rings

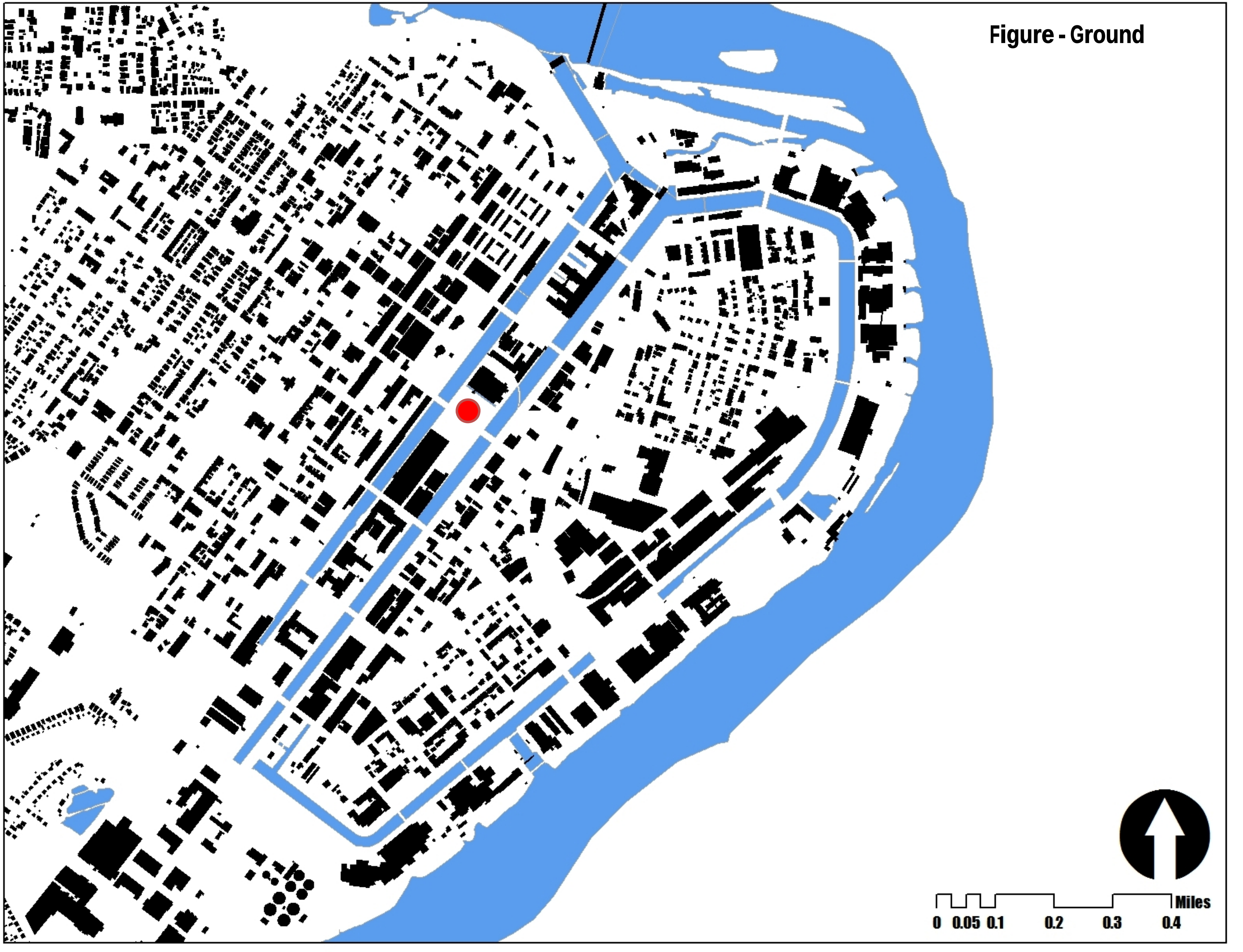
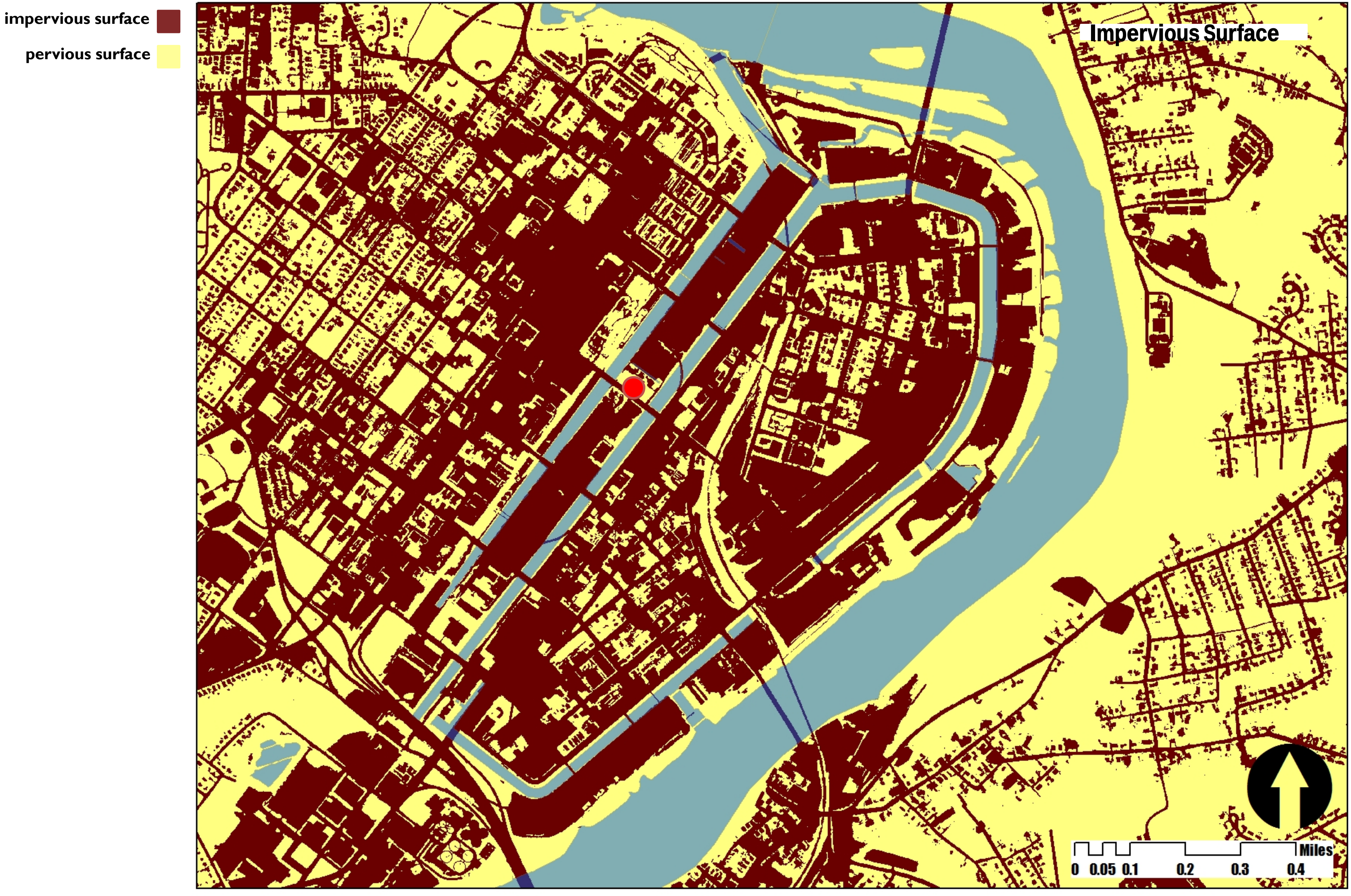
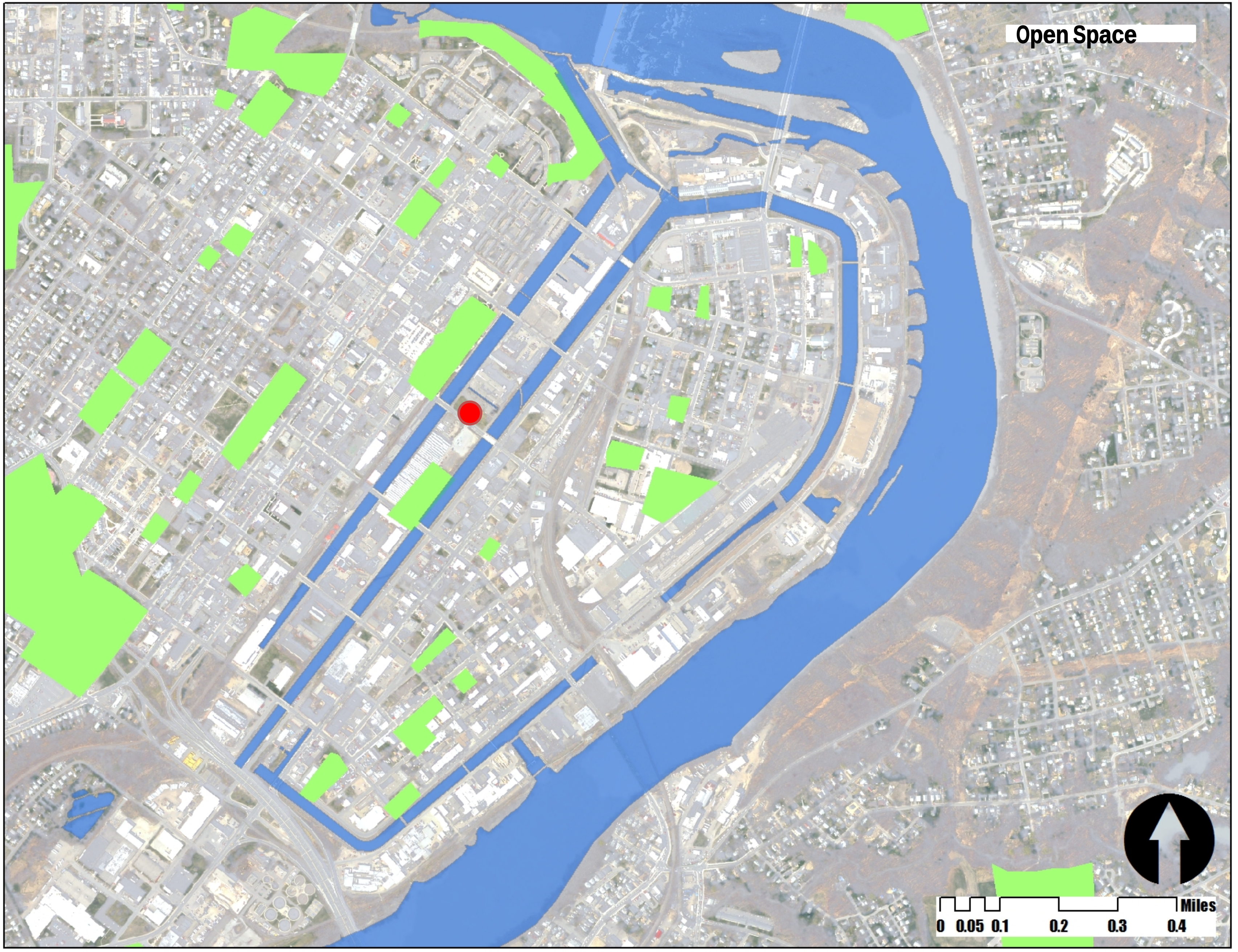


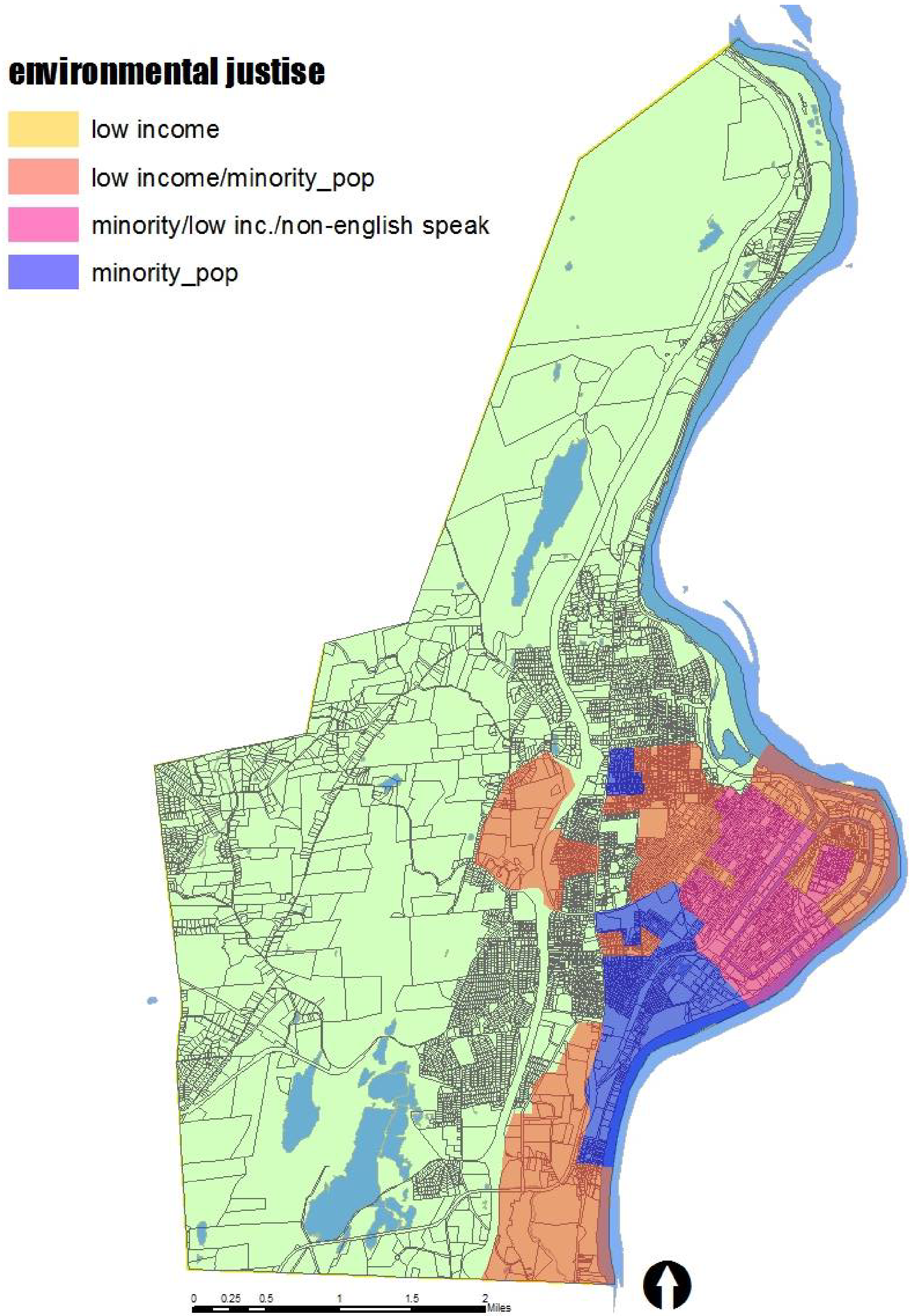
Figure - Ground
Miles
0 0.05 0.1 0.2 0.3 0.4


impervious surface
pervious surface
Impervious Surface
0 0.05 0.1 0.2 0.3 0.4
Miles


Open Space
Miles
0
0.05
0.1
0.2
0.3
0.4

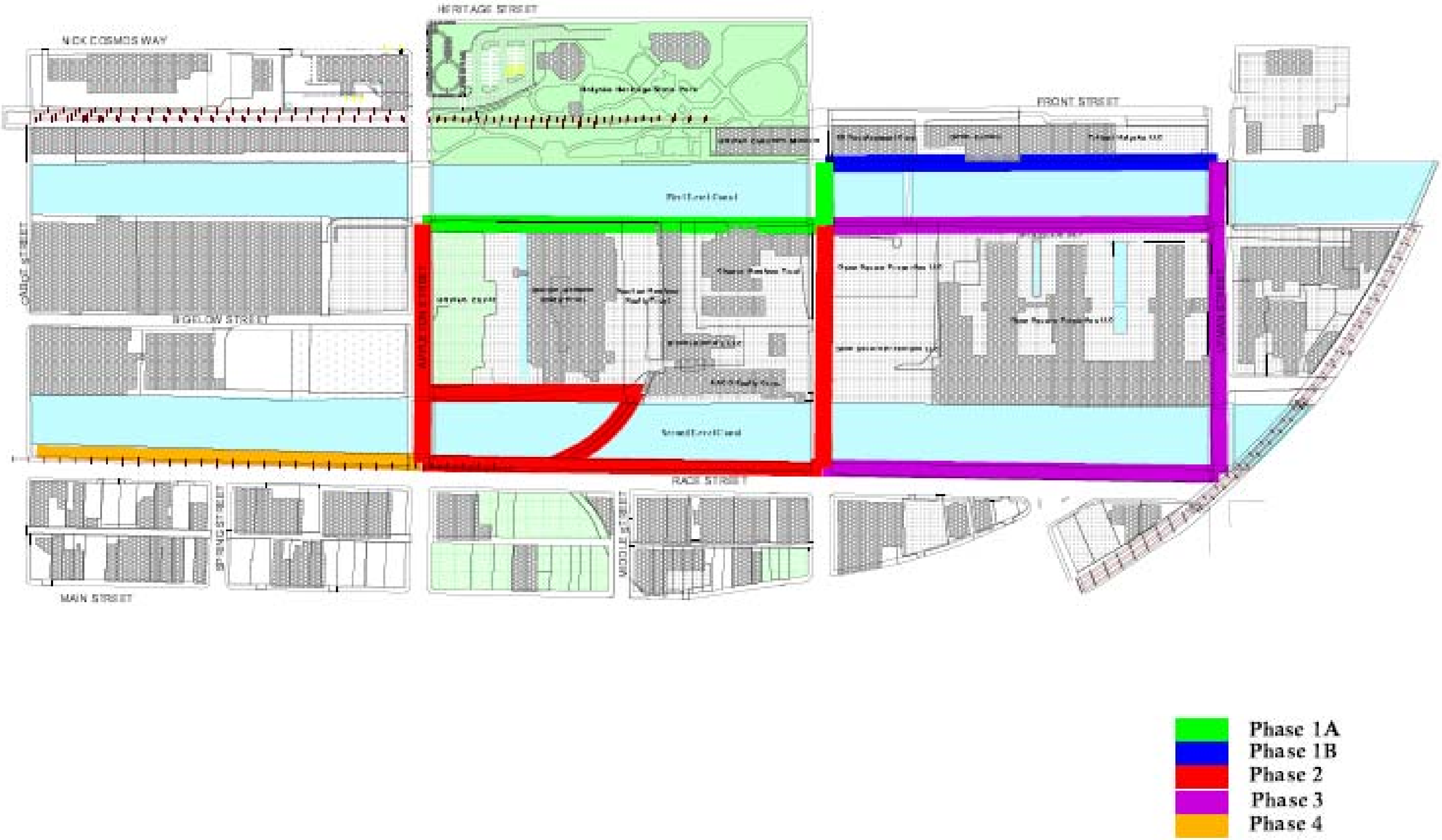

ASSESSED BROWNFIELDS
0 0.05 0.1 0.2 0.3 0.4
Miles


HOLYOKE BROWNFIELD REDEVELOPMENT PRIORITY
Holyoke Brownfield Redevelopment Priority
Brownfields_137_08_06.SCORE
Lowest Priority
Medium
Highest Priority
Miles
0 0.05 0.1 0.2 0.3 0.4

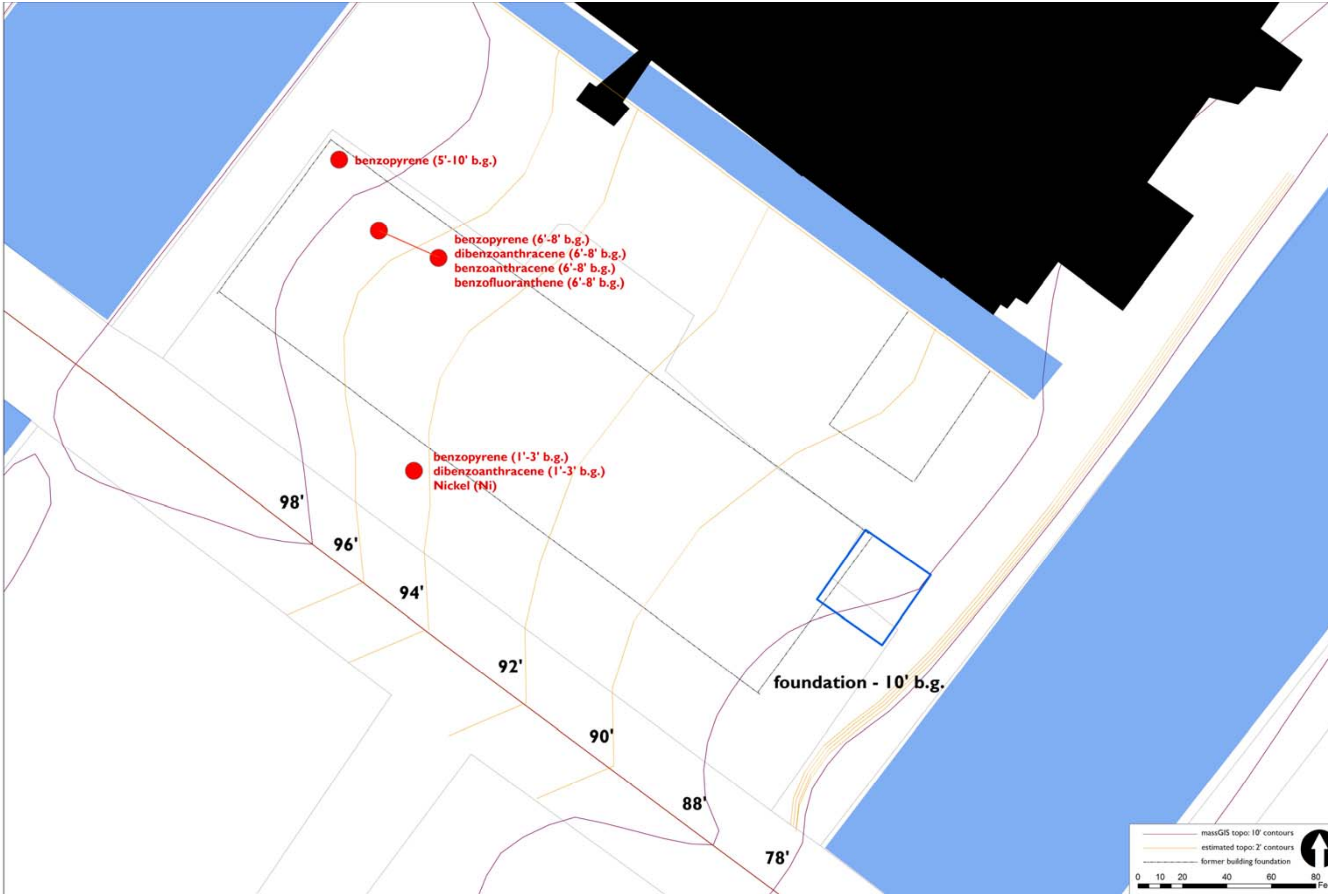


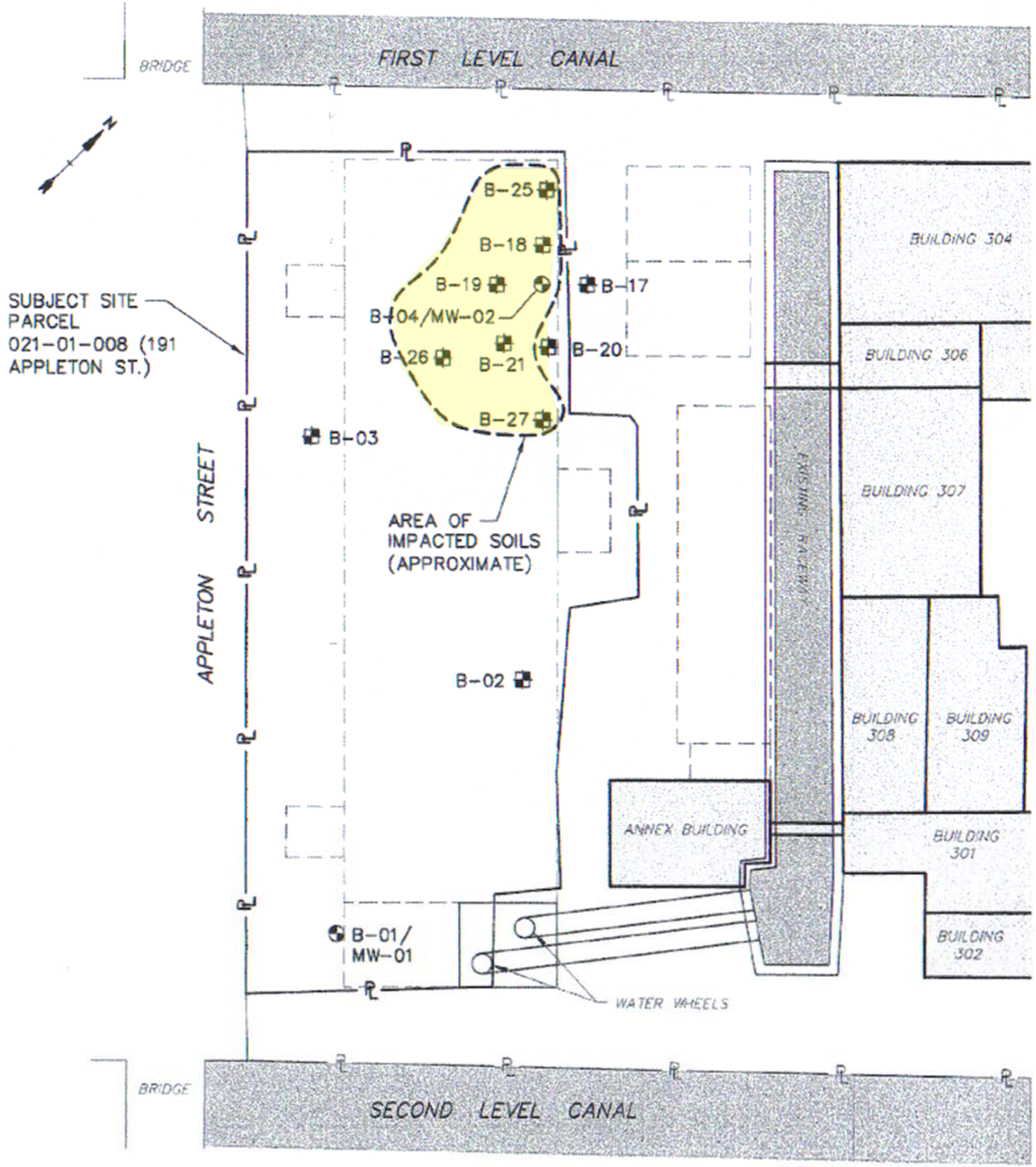
environmental justise
low income
low income/minority_pop
minority/low inc./non-english speak
minority_pop
0
0.25
0.5
1
1.5
2
Miles

Holyoke Canalwalk



Miles
0 0.004 0.008 0.016 0.024 0.032


benzopyrene (5'-10' b.g.)
benzopyrene (6'-8' b.g.)
dibenzoanthracene (6'-8' b.g.)
benzoanthracene (6'-8' b.g.)
benzofluoranthene (6'-8' b.g.)
benzopyrene (1'-3' b.g.)
dibenzoanthracene (1'-3' b.g.)
Nickel (Ni)
98'
96'
94'
92'
90'
88'
78'
foundation - 10' b.g.
massGIS topo: 10' contours
estimated topo: 2' contours
former building foundation
0 10 20 40 60 80
Feet



NOTES:

1. DASHED LINE INDICATE LOCATIONS OF FORMER STRUCTURES.
2. LOCATIONS OF ALL BUILDINGS, STRUCTURES AND PROPERTY LINES ARE APPROXIMATE. INFORMATION TAKEN FROM A PLAN PROVIDED BY THE HOLYOKE GAS & ELECTRIC AND TITLED "AN APPROXIMATE MAP OF THE MERRICK THREAD CO. DIV.#2 MILL OF THE AMERICAN THREAD CO." (PLAN DATE AND PREPARER UNLISTED), AS WELL AS SANBORN FIRE INSURANCE MAPPING AND HOLYOKE ASSESSOR'S MAPPING.
3. LOCATIONS OF SOIL BORINGS (EXCEPT BORINGS B-17 THROUGH B-21 AND B-25 THROUGH B-27) AND MONITORING WELLS WERE SURVEYED BY E.B. HOLMBERG & ASSOCIATES OF CHESTERFIELD, MASSACHUSETTS. ALL OTHERS SAMPLING LOCATIONS ARE APPROXIMATE.

LEGEND

SOIL BORING

MONITORING WELL

PROPERTY LINE

FIGURE 4

BROWNFIELDS CLEANUP SITE PLAN

FORMER ADAMS PAKKAWOOD SITE
191 APPLETON STREET
HOLYOKE, MASSACHUSETTS

TIGHE & BOND INC. CONSULTING ENGINEERS
WESTFIELD, MASSACHUSETTS

SCALE: 1" = 50' DATE: FEBRUARY 2009

H1295/SITE1RAM

Summary of Soil Results - Former Adams Paklawood Property

191 Appleton Street, Holyoke, Massachusetts

(Results in milligrams per kilogram - mg/kg)

Sample ID	B-01	B-03	B-04	B-04	B-18	B-18	B-19	B-20	B-21	B-25	B-26		Method 1 Cleanup Standards			Method
Sample Depth	0-5'	1-3'	6.5-8'	11-13'	5-8'	8-10'	5-10'	8-10'	6-8'	5-10'	5-6'					
Sample Date	4/27/04	4/28/04	4/28/04	4/28/04	8/16/04	8/16/04	8/16/04	8/16/04	8/16/04	10/13/04	10/13/04					
PID reading (ppm)	0	0	0	0.1	0.5	0.1	0	0	0	0.1	0					
Dexsil reading (ppm)	-	-	-	1,532	> 2,000	11	1,763	407	1,685	725	423	S-1/GW-2	S-1/GW-3	S-3/GW-2	S-3/GW-3	UCLs
VOCs [1]																
n-Propylbenzene	-	-	-	< 0.099	-	-	-	-	-	-	-	NE	NE	NE	NE	NE
p-Isopropyltoluene	-	-	-	< 0.099	-	-	-	-	-	-	-	NE	NE	NE	NE	NE
sec-Butylbenzene	-	-	-	< 0.099	-	-	-	-	-	-	-	NE	NE	NE	NE	NE
Tetrachloroethene	-	-	-	< 0.099	-	-	-	-	-	-	-	10	30	2	2,000	10,000
1,2,4-Trimethylbenzene	-	-	-	< 0.099	-	-	-	-	-	-	-	NE	NE	NE	NE	NE
1,3,5-Trimethylbenzene	-	-	-	< 0.099	-	-	-	-	-	-	-	NE	NE	NE	NE	NE
o-Xylene	-	-	-	< 0.099	-	-	-	-	-	-	-	300	500	300	3,000	10,000
EPH Carbon Ranges																
C_9-C_{18} Aliphatic	-	< 4.1	48	210	270	< 4.0	210	< 4.2	32	-	6.1	1,000	1,000	5,000	5,000	20,000
C_{11}-C_{22} Aromatic	-	92	580	2,200	1,800	< 4.0	2,000	6.1	580	-	360	1,000	1,000	5,000	5,000	10,000
C_{19}-C_{36} Aliphatic	-	19	4,100	16,000	26,000	13	17,000	14	1,300	-	460	3,000	3,000	5,000	5,000	20,000
EPH Target Analytes																
Acenaphthene	-	0.78	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	2.1	-	0.7	1,000	1,000	5,000	5,000	10,000
Acenaphthylene	-	< 0.41	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	1.5	-	< 0.4	600	10	600	10	10,000
Anthracene	-	1.3	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	8.4	-	2.5	1,000	1,000	5,000	5,000	10,000
Benzo(a)anthracene	-	4.2	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	21	-	< 0.4	7	7	300	300	3,000
Benzo(a)pyrene	-	3.9	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	19	-	< 0.4	2	2	30	30	300
Benzo(b)fluoranthene	-	4.7	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	11	-	< 0.4	7	7	300	300	3,000
Benzo(g,h,i)perylene	-	2.2	3.4	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	5	-	< 0.4	1,000	1,000	5,000	5,000	10,000
Benzo(k)fluoranthene	-	2.9	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	15	-	< 0.4	70	70	3,000	3,000	10,000
Chrysene	-	4.4	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	12	-	< 0.4	70	70	3,000	3,000	10,000
Dibenzo(a,h)anthracene	-	1.6	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	6.1	-	< 0.4	0.7	0.7	30	30	300
Fluoranthene	-	11	4.5	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	40	-	14	1,000	1,000	5,000	5,000	10,000
Fluorene	-	0.6	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	3	-	1.4	1,000	1,000	5,000	5,000	10,000
Indeno(1,2,3-cd)pyrene	-	1.6	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	2.9	-	< 0.4	7	7	300	300	3,000
2-Methylnaphthalene	-	< 0.41	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	< 1.1	-	0.53	80	300	80	500	5,000
Naphthalene	-	< 0.41	< 2.2	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	1.7	-	1.2	40	500	40	3,000	10,000
Phenanthrene	-	7.3	2.7	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	31	-	12	500	500	3,000	3,000	10,000
Pyrene	-	8.5	3.4	< 3.9	< 8.2	< 0.40	< 8.0	< 0.42	30	-	7	1,000	1,000	5,000	5,000	10,000
SVOCs (via 8270) [1]																
Phenols	-	-	-	ND*	-	-	-	-	-	< 4.7	-	NE	NE	NE	NE	NE
Phenanthrene	-	-	-	ND*	-	-	-	-	-	2.9	-	500	500	3,000	3,000	10,000
Fluoranthene	-	-	-	ND*	-	-	-	-	-	5.0	-	1,000	1,000	5,000	5,000	10,000
Pyrene	-	-	-	ND*	-	-	-	-	-	4.3	-	1,000	1,000	5,000	5,000	10,000
Benzo(a)anthracene	-	-	-	ND*	-	-	-	-	-	2.7	-	7	7	300	300	300
Chrysene	-	-	-	ND*	-	-	-	-	-	2.6	-	70	70	3,000	3,000	10,000
Benzo(b)fluoranthene	-	-	-	ND*	-	-	-	-	-	3.1	-	7	7	300	300	3,000
Benzo(k)fluoranthene	-	-	-	ND*	-	-	-	-	-	2.7	-	70	70	3,000	3,000	10,000
Benzo(a)pyrene	-	-	-	ND*	-	-	-	-	-	2.9	-	2	2	30	30	300
Indeno(1,2,3-cd)pyrene	-	-	-	ND*	-	-	-	-	-	1.4	-	7	7	300	300	3,000
Benzo(g,h,i)perylene	-	-	-	ND*	-	-	-	-	-	1.4	-	1,000	1,000	5,000	5,000	10,000
MCP Metals																
Mercury	0.059	0.59	-	-	-	-	-	-	-	-	-	20	20	30	30	300
Antimony	< 6.2	< 7.6	-	-	-	-	-	-	-	-	-	20	20	30	30	300
Arsenic	< 3.1	9.6	-	-	-	-	-	-	-	-	-	20	20	20	20	200
Barium	< 3.1	120	-	-	-	-	-	-	-	-	-	1,000	1,000	5,000	5,000	10,000
Beryllium	< 0.62	< 0.63	-	-	-	-	-	-	-	-	-	100	100	200	200	2,000
Cadmium	< 0.62	< 0.48	-	-	-	-	-	-	-	-	-	2	2	30	30	300
Chromium	< 3.1	26	-	-	-	-	-	-	-	-	-	30	30	200	200	2,000
Lead	< 3.1	160	-	-	-	-	-	-	-	-	-	300	300	300	300	3,000
Nickel	< 0.62	22	-	-	-	-	-	-	-	-	-	20	20	700	700	7,000
Selenium	< 3.1	< 1.1	-	-	-	-	-	-	-	-	-	400	400	800	800	8,000
Silver	< 3.1	< 0.26	-	-	-	-	-	-	-	-	-	100	100	200	200	2,000
Thallium	< 3.1	< 3.8	-	-	-	-	-	-	-	-	-	8	8	80	80	800
Vanadium	< 3.1	37	-	-	-	-	-	-	-	-	-	600	600	1,000	1,000	10,000
Zinc	< 15	220	-	-	-	-	-	-	-	-	-	2,500	2,500	5,000	5,000	10,000
PCBs																
All Arochlors	< 0.12	< 0.12	-	< 0.11	-	-	-	-	-	-	-	2	2	2	2	100
Cyanide																
Total cyanide	< 1.2	-	-	< 1.2	-	-	-	-	-	-	-	100	100	400	400	4,000
Microscopic																
Coal	Detected	-	Detected	-	-	-	-	-	-	-	-	-	-	-	-	-
Asphalt	-	-	Detected	-	-	-	-	-	-	-	-	-	-	-	-	-
Wood Ash	Detected	-	Detected	-	-	-	-	-	-	-	-	-	-	-	-	-
Oil/Tar	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1] Only VOCs and SVOCs that were detected above laboratory reporting limits in one or more of the soil samples are included in the table.

Boxed value indicates concentration in soil sample exceeds MCP Method 1 Cleanup Standard (standards referenced are prior to when changes in the MCP became effective on April 3, 2006).

<10 indicates compound was not detected above the indicated laboratory reporting limit.

ND* indicates that no analyte was detected above laboratory reporting limits in any of the respective samples, and one or more of the reporting limits exceeds one or more applicable RCS-1 values.

NE indicates no RC or Method 1 Cleanup Standard has been established

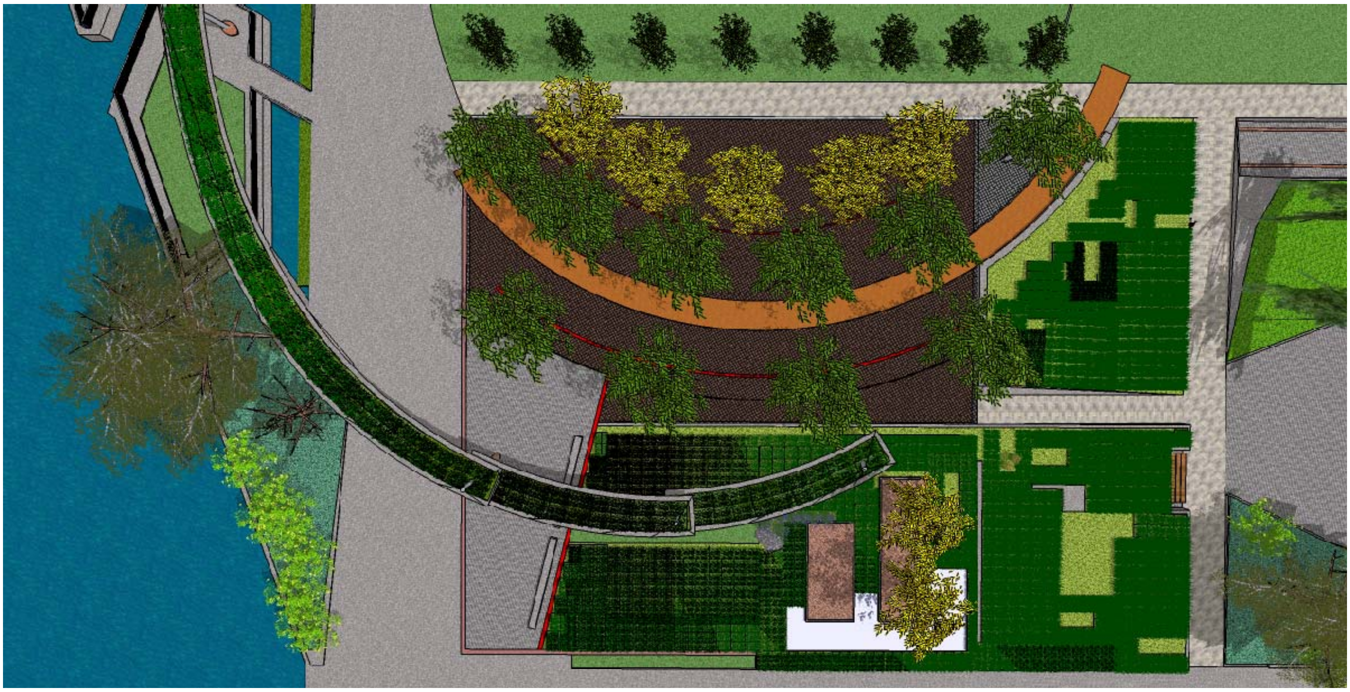
PLAN VIEW

PLAN VIEW – Remediation Park

BIRDSEYE – Remediation Park

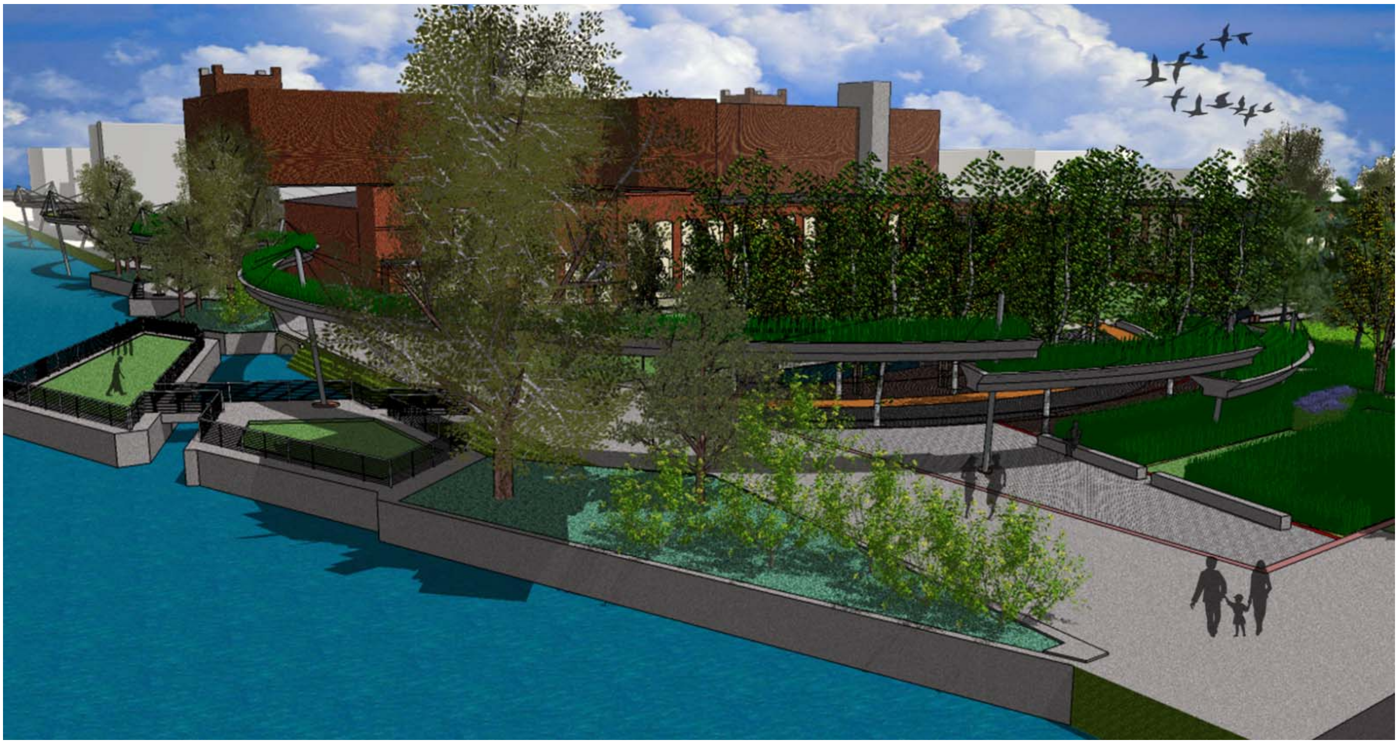
skyREM – Remediation Park

PLAN VIEW – Remediation Zone (west)

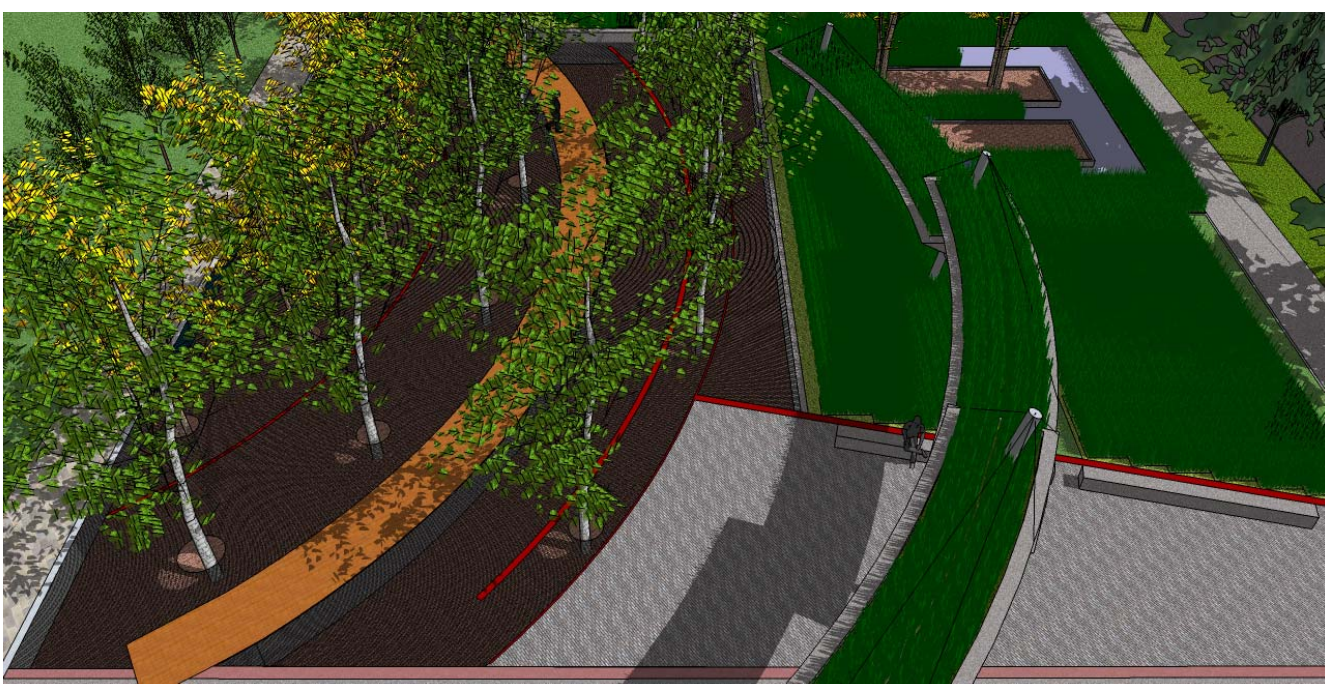


PLAN VIEW – Treetrain Plaza (east)

Views – Northeast



skyREM entering REMpark- overhead

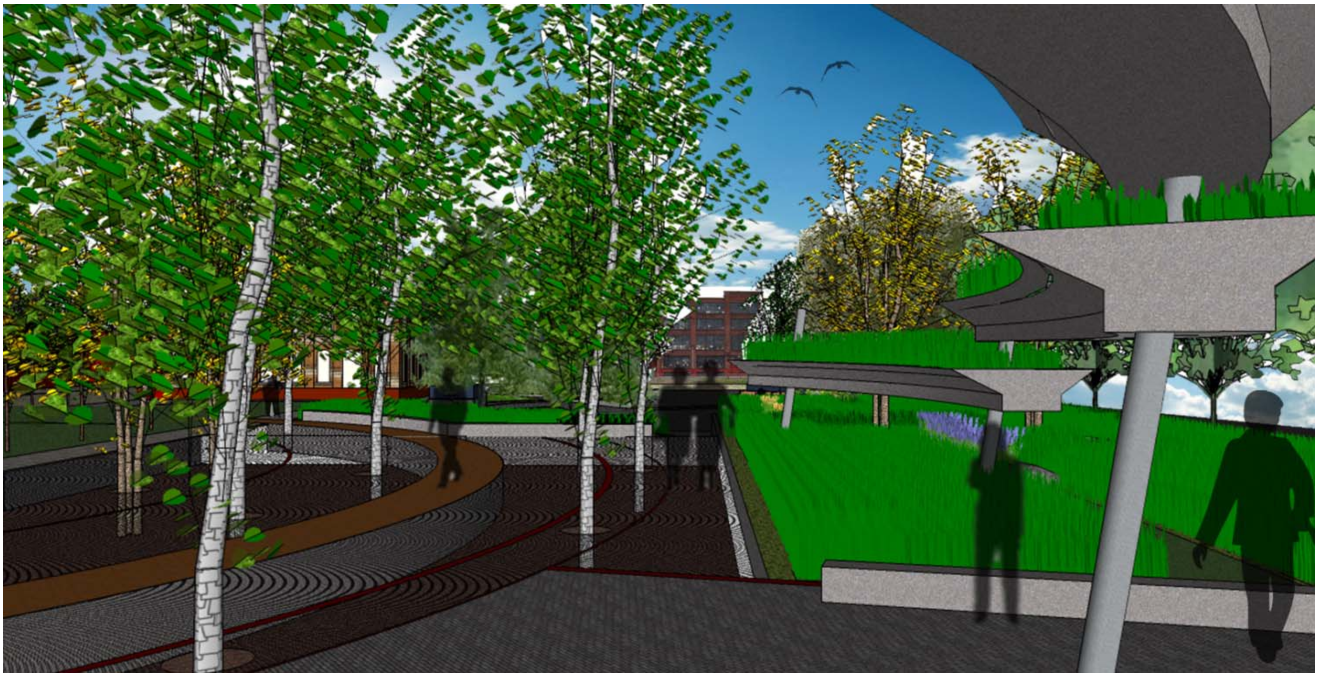


skyREM structure (SW)

Open green, skyREM, & canal wetland (E)

East entrance w/hydro-wheel

Rem –zone looking east



Tree-train plaza looking west to skyREM entry

Accessibility entrance ramp (eastside)

Tree-train plaza spaces

Tree-train mobile

Tree-train plaza - dynamic spaces