Enhancement of Concretized Streams: Mill Creek

THESIS

Presented in Partial Fulfillment of the Requirements for the Degree Master of Landscape Architecture in the Graduate School of The Ohio State University

By

Brett Nathan Kordenbrock

Graduate Program in Landscape Architecture

The Ohio State University

2013

Thesis Committee:

Jacob Boswell, Assistant Professor, Advisor

Deborah Y. Georg, Associate Professor, Member

Abstract

An increase in the understanding of anthropogenic impacts related to our waterways has spurred much interest in ecological stream restoration. Billions of dollars are entering this field as societal and regulatory pressures are exerted upon municipalities and developers. Research suggests that stream restoration projects only consider aesthetics and economic growth as key goals rather than thinking of how the stream functions holistically or ecologically. Additionally, research suggests that these funds are greatly misused, funding only stream restoration projects where space, politics, and infrastructure allow (Nilsson et al 2003, and Niezgoda and Johnson 2005). These projects cater toward a naturalized condition. A variety of techniques and strategies are deployed to achieve both project goals and objectives. These techniques and strategies support the notion of a naturalized stream condition through their effective use and aesthetics. Furthermore, research shows that goals and objectives for these projects can be lumped in to four main categories: bank stabilization, erosion control, stormwater management, and re-vegetation (Bernhardt and Palmer 2007). However, little is being done by way of research and design study in the most severely degraded portions of these streams—those that are concretized.

The goal of this study is to show how restoration might occur in concretized waterways where a naturalized condition cannot fully accommodate the degree of changes and demands that have been placed on the watershed by urbanization.

Objectives within this study focus on improvements to water quality and in-stream habitat as well as accessibility and connectivity for communities. Through the review of traditional stream restoration techniques, their hybridization, and deployment in concretized streams this project shows how a highly degraded stream condition can be augmented to perform similarly, ecologically, to its naturalized counterpart.

A catalog of traditional stream restoration techniques from both the United States Department of Agriculture (USDA) and the United States Army Corp of Engineers (USACE) is compiled to understand how these techniques are effective, their tectonics, and positioning. Based on project goals and objectives the traditional techniques are hybridized to broadly applicable concretized stream conditions—trapezoidal and vertical embankments. From here, these hybrids are deployed within Sections 3 and 4A of the Lower Mill Creek, Cincinnati, Ohio. Sectional and vignette drawings are used to understand the materiality, connections, and interaction of they hybrid types. This method of investigation yields a catalog of 30 hybrid interventions for the enhancement of concretized waterways.

Finally, this study considers what could become of the Mill Creek if thought of as a critical infrastructure—one that has to accommodate industrial and flood control concerns as well as ecological and social concerns. One that is an asset to adjacent communities, promotes revitalization, and is ecologically productive. This lens brings about new layers upon which the Lower Mill Creek can be engaged and re-imagined.

Dedication

This document is dedicated to my family. Your enduring support, encouragement and love have helped me realize some of my deepest dreams and dreams I never knew I had. Thank you.

Acknowledgments

I would like to first thank Professor Jacob Boswell for his steadfast spirit, support, and guidance throughout both my tenure at the Knowlton School of Architecture and this thesis project. Jacob has continually inspired me in ways I could not have conceived before entering this program. He has been a role model both academically and personally. His explorations and interests have cultivated new agency in both my thoughts and work. Thank you, Deborah Georg for your challenges. Your knowledge, questions, and guidance have aided me in understanding the complexity of design problems and the importance of representation in relation to the stakeholders to whom this project will serve. This has helped in crafting not only a clear and concise argument, but also an understanding of the designer/client relationship. To Jason Kentner, 'What do you think?' This question will forever facilitate argument and narrative building as well as decision-making. Thanks also to David Whittaker whose resourcefulness and feedback was instrumental in this process. Finally, to the entire landscape architecture faculty that I have had the honor of collaborating with and working under; you have all inspired me in ways I never thought possible. You have all made my tenure at the Knowlton School of Architecture exceed every one of my expectations. Without question both you and my cohort have made this the most enjoyable and invigorating experience of my life. Thank you.

Vita

October 16, 1983................................Born-Cincinnati, Ohio

2002..Northwest High School

2007..B.U.P-Urban Planning, University of Cincinnati

2011 to present…...............................Graduate Teaching Associate, Department of Landscape Architecture, The Ohio State University

Publications

2008..Green Infrastructure and Site Design, Ohio, Kentucky and Indiana Planning Conference

2009..Making Cents of LEED, Kentucky Planning Magazine

2009..Making Cents of LEED, Ohio Planning Magazine

2013..Enhancement of Concretized Streams, ATMOSPHERE 5: Design & Ecology Symposium, University of Manitoba

Awards

2013..Student Merit Award, American Society of Landscape Architects

2012..University Olmsted Scholar, Landscape Architecture Foundation

2012..Inductee, Sigma Lambda Alpha Honor Society

2012..Design Excellence, Urban Landscape Design Studio, Visiting Professor Curtis Roth

2012..Winner, The Dean's 24-Hour Design Competition, The Ohio State University, College of Engineering

2011..Student Honor Award, Ohio Chapter of the American Society of Landscape Architects

2011..Winner, *I am Being Resourceful* Design Competition, Association of Collegiate Schools of Architecture, ARCHIVE100

2011..Faculty Prize, First Year Graduate, Department of Landscape Architecture

2011..Cultural and Social Design Sensitivity, Urban Landscape Design Studio, Lecturer Karla Trott

2010..Overall Design Development, Urban Landscape Design Studio, Assistant Professor Jason Kentner

Fields of Study

Major Field: Landscape Architecture

Table of Contents

List of Figures

Chapter 1: Introduction

Degradation of waterways has severely impacted biological and ecological function. Anthropogenic impacts such as: catchment area imperviousness, sediment and erosion control inefficiencies, riparian buffer marginalization, channelization and concretization, point source and diffuse pollution, have been examined and understood to have negative impacts on freshwater riverine ecosystems (Giller 2005). Ecological restoration efforts aim to recover damaged and degraded ecosystems through a wide range of techniques and perspectives (Hobbs and Cramer 2008). This need is derived from a greater understanding of the important ecological services these water systems perform—habitat connection and cover, water purification, sequestration, food resources, and aesthetic and recreational outlets (Giller 2005).

Too often stream restoration projects are approached through social and economic lenses. Primary goals of bank stabilization, flood control, beautification, commercial property redevelopment, and recreational or park development are identified and measured for success. These projects rarely consider the ecological systems at work or the value they have in terms of ecosystem services (Otto, et al 2004, and Palmer et al 2005). Areas where space allows: where floodplains can be expanded, banks re-graded or re-engineered and planted, and where the public can re-engaged the water are typical sites of these restoration projects (Bernhardt and Palmer 2007).

A chain is only as strong as its weakest link. This axiom expresses the nature of the urban stream restoration approach. With billions of dollars of investment in projects that return these systems to a naturalized condition, little is being explored in the concretized sections of urban streams. Because these sections are extremely constrained, by abutting development and infrastructures, the ability to intervene is seen as insurmountable. This underutilization of constrained waterways is a result of regulatory agency control, a utilitarian mindset that sees these channels as nothing but large conveyance swales (Bernhardt and Palmer 2007), and lack of funding for what is considered under-researched and therefore not practical to receive funds. This conundrum has limited research into restoration of the most severely degraded stream conditions. Jansson, et al (2007) identify several considerations for future research; one being that "the potential to restore ecosystem processes under highly constrained conditions" should be explicitly taken into account in our restoration efforts

This project is a positioned in response to two gaps in both literature and research of ecological stream restoration. One, stream restoration practices are exclusively deployed in areas where space, politics, and infrastructure allow. They take advantage of and promote traditional restoration techniques that cater toward the natural. Two, there is a definitive gap in how we think of and engage concretized streams. There is little discourse and therefore research focused on these highly degraded channels.

The goal of this study is to show how restoration might occur in concretized waterways where a naturalized condition cannot fully accommodate the degree of changes and demands that have been placed on the watershed by urbanization.

Furthermore, if we think about these concretized waterways differently they might be able to perform as well as naturalized stream restoration projects. Objectives within this study focus on improvements to water quality and in-stream habitat as well as accessibility and connectivity for residents and users. Through the review of traditional stream restoration techniques, their hybridization, and deployment in concretized streams this project shows how a highly degraded stream condition can be augmented to perform, ecologically, similarly to its naturalized counterpart.

This study argues that the current stream restoration approach is performing only three main functions: re-vegetation, environmental aesthetics, and flood control. Through design studies, the project will show how new programmatic layers and design interventions can further augment existing ecological conditions within the Lower Mill Creek, Cincinnati, Ohio (see Figure 1).

Figure 1. Mill Creek at Ivorydale (Kordenbrock, 2012)

Chapter 2: Literature Review

Restoration in Ecology

“The next century will, I believe, be the era of restoration in ecology”

- E.O. Wilson (1992)

Only until recently has restoration ecology, and more importantly, stream restoration been considered a discipline or specific area of study. A timeline of stream restoration is fitting in examining its history and potential future. In 1964 *Fluvial Processes in Geomorphology* was published by Luna B. Leopold. This core text gave rise to the concern and awareness of the accelerated changes in stream make-up, flow dynamics, and biology. The establishment of the Clean Water Act in 1972 placed regulations on pollutant discharges into navigable waters, maintained requirements for water quality standards, funded construction of remediation projects (specifically treatment plants), and gave the Environmental Protection Agency (EPA) authority to control and set water quality and discharge requirements (Summary of the Clean Water Act 2012). This Act put a new focus on water quality. It necessitated new ways of understanding and acting on our water bodies. Early restoration ecologists and promoters like Rosgen, Harvey and Watson produced the first wave of studies and guidelines suggesting new methods by which rivers, streams and other water bodies should be handled. These acts propelled ecological restoration into the minds of policy makers, city officials, designers, public, and scientists across the globe. Continued refinement of guidelines and handbooks has led to new strategies of application, but also critique of the projects themselves, restoration goals, and techniques ("Beargrass Creek Revisited – A Perspective on the Evolution of Stream Restoration over the Past 15 Years", and Hobbs 2006). These efforts have been part of a larger reaction and understanding of anthropogenic impacts on our natural environment and how best manage them.

Population pressures have forced us to see, react to, and manage the damages we have catalogued. As both a mediator and applier of restoration efforts, Restoration Ecology fills the gap between forestry, wastewater technologies, reclamation, and other fields related to the relief of disturbance. Current restoration approaches in urban streams are largely constituted by reducing channel erosion and promotion of channel stability (Bernhardt and Palmer 2007). Furthermore, Bernhardt and Palmer categorize contemporary restoration efforts into four main groups: stormwater management, bank stabilization, channel reconfiguration and grade control, and riparian replanting and vegetation management (2007). Each is used depending on project goals and objectives.

Additionally, these restoration efforts take place laregely in highly developed urban areas. A National River Restoration Science Synthesis (NRRSS) showed that urban streams receive a disproportionate amount of funds for projects. In Maryland half of all funds for restoration projects went to four of the twenty-three most densely populated counties. These funds and associated projects were designed to maintain infrastructures and edges along industrial and other high dollar properties in major urban growth areas (Bernhardt 2007, and Bernhardt 2005).

Preventing lateral movement is seen as necessary for maintaining land values and ensuring public safety. So, while restoration projects do contribute a performative layer of vegetation that improves bio-diversity and enhances pollutant uptake, they are still highly controlled, engineered systems. The vegetative layer thus serves a dual purpose, to stabilize and enhance biodiversity while also serving as a publicly acceptable aesthetic mask for what is still, at root, a highly engineered piece of stormwater infrastructure. Could these systems perform in more robust ways if restoration engineering did not limit itself to interventions that mimic "natural" aesthetics, but rather were open to a visual language, which acknowledges that "restored" rivers and streams remain highly engineered infrastructures?

Urban streams are plagued with constraints. Sites are hard to select for reasons ranging from entitlement to access to clean up of brownfields. Nilsson et al. (2003) point out "restoration options for urban streams are highly constrained by available land, urban infrastructure, political pressures, and a lack of technical knowledge about how to apply standard restoration techniques in urban settings" (Nilsson, et al. 2003; Niezgoda and Johnson 2005). In many urban contexts, restoration managers must make concessions "between the ideal restoration design for achieving management goals and the restoration design that will fit within the available space" (Bernhardt and Palmer 2007).

Increasing concern within ecological stream restoration is the logic informing reference imagery for restoration projects. "[…] selecting a reference condition based purely on geomorphic features (e.g. Rosgen) must be done with extreme caution and more sophisticated approaches are required that incorporate empirical data on water and sediment flux through the target stream" (Kondolf 1995, Juracek and Fitzpatrick 2003, and Shields, et al 2003). This is mainly attributed to the success and failure rates of re-configured projects in urban catchment areas. This narrow focus only considers an ideal state for the project, not taking in to account how ecological and geomorphologic processes might impact the stream. Many projects are also assumed to work as well as reference conditions and therefore reconfigurations have become common despite lack of data on their effectiveness (Bernhardt and Palmer 2007). These results are due in large part to assumptions made about the volume of the stream, fluctuations in water levels, and theoretical conditions that are not measured or have yet to be substantiated. However, new strategies for assessing success in stream restoration projects are being developed and tested. Woolsey, et al explores new strategies for assessing success in stream restoration projects. This paper outlined ecological and social objectives for restoration. From here, Woolsey proposed several indicators of success for each objective (2007). These objectives are considered as they relate to ecological performance and success in stream restoration projects. Criticism of these approaches and goals has come from both academic and professional circles the likes of Richard Hobbs and David Fletcher. With rapid climate change and an increase in the application and understanding of ecological principles new thoughts and ideas are being proposed.

Challenges to traditional techniques in ecological stream restoration (biotechnical engineering, bank re-grading and stabilization, in-stream habitat structures, re-vegetation strategies for terrestrial and riparian zones, and natural channel design (Otto, et al 2004)) has been put forth by Bernhardt, Thompson, and Palmer, among others. In *Novel* *ecosystems: theoretical and management aspects of the new ecological world order*, Richard Hobbs posits that most ecosystems have been touched, in one-way or another, by humans. Because of the manipulation of ecosystems by humankind we need to understand what values and role these novel ecologies play. Hobbs argues it is important to support these well-established ecologies because of their stable state (2006). This approach is interesting because it suggests that novel ecologies could be just as effective, if not more effective, than naturalized ecologies introduced through re-vegetation. The value comes from understanding why these systems are operating and to what extent they can be valued in the larger successional picture (see Figure 2).

Similarly, David Fletcher's *Flood Control Freakologies: Los Angeles River Watershed* buttresses the idea that novel ecologies provide ecosystem services as well. In his paper, Fletcher argues that the "freakologies" that exist in the Los Angeles River are misunderstood, "we need to develop new narratives to understand and appreciate urban watersheds and how they function: where the water flows, what flows in them, who uses, owns, and manages them, how they function, what they are connected to, and what ecologies exist in them" (2008). Furthermore, David Fletcher argues that the pervasive desire to return it (the Los Angeles River) to its natural state is hopeless (see Figure 3). This perspective is seminal to how we must retool and rethink these utilitarian structures. With these theories in mind, there are a growing number of projects that have tried to apply new technologies and scientific understanding to ameliorate the impacts we humans have made on our planet.

Figure 2. Novel Ecologies (Kordenbrock, 2012)

Figure 3. Los Angeles River (http://inhabitat.com/the-la-river/, 2009) (Erik Gauger)

Biologist and ecological designer John Todd is a pioneer in augmented ecological systems. Since the 1970's Todd's work at the New Alchemy Institute has both developed and tested biological theories of how ecological systems can solve some major human issues. The application of biological research into technologies that help solve human needs of food production and waste treatment has resulted in "living machines". These "machines" involve microorganisms, fish, and plants in a process to treat water, but also serve as food production, fuel generation, waste conversion, water purification, chemical detoxification, environmental restoration, and advanced ecologically engineered systems (AEES) (Todd 2010, and Todd, et al 2003). Todd has designed projects such as the Baima Canal Restorer in Fuzhou, China (see Figure 4).

Figure 4. Baima Canal Restorer (http://toddecological.com/company/, 2012)

The Baima Canal was considered one of the most polluted waterways in the City. Through a series of plantings, aeration techniques, and an integrated floating walkway the restorer decreased odors, total suspended solids, sludge accumulation, and nitrogen loading while providing access to the waterway for the community (Todd 2010). The consideration and exploration of both advanced theory and application prefigure the potential for projects that have the capacity to use ecological processes in non-traditional settings to help ameliorate anthropogenic impacts.

Landscape Architecture: A Changing Paradigm in How and Where We Operate

Landscape architecture is a discipline that operates at multiple scales, within different territories, and with a diverse range of expertise (Hung 2011). As a profession, landscape architecture is undergoing a shift in both territory and method of operation (Georg 2011). Constructs such as Landscape Urbanism and Infrastructural Opportunism are having a profound impact on our perception of ecological and infrastructural systems and their capacity to act as an armature for accommodation of civic, industrial, environmental and recreational goals. Traditionally, landscape architects are armed with a tool kit of how to create engaging spaces, respond to culture, and be stewards of the environment. These traditions are carried through in the work we do today, but have begun to refocus our efforts in urbanized areas and with an ecological lens.

Discourse within landscape architecture has shifted to a focus on ecological systems and infrastructure utilization as critical responses to urban sustainability. We have come to realize that infrastructure (highways, energy production systems, rail, etc.) has largely been responsible for city segmentation, underutilization of land, and a bias toward the automobile. The utilitarian nature of these systems is now in question. In *Infrastructural Urbanism,* Stan Allen argues that infrastructure allows for the participation of multiple authors, that these "give direction for future work in the city not by the establishment of rules or codes, but by fixing points of service, access and structure" (1999). The control of only several factors in these systems (service, access, structure) allows for a multitude of other programmatic scenarios to play out alongside and interact with these infrastructures. This allows them to be an infrastructure for a number of networks and serve a number or purposes. Infrastructure becomes a datum where a few points are fixed and thus, allows nearby networks to emerge, engage, and interact with this critical support system.

To Allen's point, channelized watercourses are of increasing interest because of their proximity to newly identified redevelopment areas, ability to engage the public with natural systems, and their capacity to provide ecosystem services as part of a larger network. Additionally, these waterways attract billions of dollars each year. A study by the NRRSS showed that urban streams receive a disproportionate amount of funds for projects. Most of these funds were put to use to maintain infrastructures and edges along industrial and other high dollar properties in major urban growth areas (Bernhardt and Palmer 2007, and Bernhardt 2005). The restoration of these waters is crucial to plant and animal biodiversity, water quality, aesthetic appreciation, and societal objectives to better utilize dismissed and underutilized land.

In Jane Amidon's, *Big Nature*, she argues for a sixth nature. Currently we are in a landscape paradigm focused on restoration and reconciliation of nature—a fifth nature.

But, what is next? Amidon argues that post-remediation motivations must included productive, generative, and seductive concepts. These landscapes are carbon-eating, bio-fuel producing algae farms, and are part public water garden, part civic park. They are producers, living systems linked to supply and demand networks and responding to issues of food security, energy sustainability, renewable energy, and climate change. Furthermore, these new landscape projects must consider ecological function as part of the urban experience (Amidon 2010).

In Jonathan Solomon's, *13 Projects for the Sheridan Parkway*, he highlights the effects of New York City highways relative to communities. We understand that these systems have segmented communities, lands stripped from the neighborhood, and land greatly underutilized. Solomon envisions a proposal which integrates cultural institutions, allows communities to populate and occupy underutilized areas that would otherwise be left to lawnmowers sucking up funds from the local government for maintenance (2004). He is calling for augmentation of these infrastructural systems—the redesign of these highways so that they might function in multiple ways for multiple users. Solomon's ideas are important in that they position infrastructural systems as flexible and adaptive; that these systems have served in limited capacity for many years and as we reinvest in them we have the opportunity to inform how these systems perform and provide a greater number of services beyond their once singular function.

Chapter 3: Methodology I—Development of Hybrid Catalog

The project began with the review of both literature and design projects focused on stream and river restoration. This survey was drawn from academic journals, design competitions, and built projects. These were reviewed in order to identify primary aspects of research and restoration actions in urban watersheds. From these sources primary positions emerged: 1) current restoration projects focus on four main functions: bank stabilization, flood control, channel reconfiguration, and aesthetics (replanting) (Bernhardt and Palmer 2007) and therefore consider ecological function as a quinary goal, and 2) there is little discourse, research, or investment focused on the most heavily degraded and concretized portions of riverine systems. These findings formed the basis for the research question: could an urban concretized stream channel be adapted and modified in order to become a contributing component of an urban river restoration?

A key metric, the Index of Biological Integrity (IBI) rating, rates streams based on current fish populations and diversity. This indicator is critical in understanding the biology, health, and chemistry of streams. The IBI provides a starting point from which designers and scientists can begin to react. Additionally, the Qualitative Habitat Evaluation Index (QHEI) is a key measure of physical characteristics for habitat in riverine ecosystems. The IBI and QHEI combined indicate allow us to better understand, holistically, physical and biological conditions within the stream. These indicators are important in defining which zones may be in need of the most help and therefore intervention.

Several sources were consulted to understand typical goals and objectives for restoration projects. A design notebook was developed for the Willamette River in Portland, Oregon. This notebook outlined the specific goals of the project. Within each goal, objectives were identified in order to carry out the specific goal. Each objective was then put through a series of questions about conditions along the river. Design proposals were then referenced based on the objective and condition in which you were designing. This notebook provided a series of objectives that focused on ecological concerns like water quality and animal habitat as two key indicators of stream integrity (Willamette Riverbank Design Notebook 2001).

Woolsey, et al also explores new strategies for assessing success in stream restoration projects. This paper outlined ecological and social objectives for restoration. From here, Woolsey proposed several indicators of success for each objective (2007). These objectives are considered as they relate to ecological performance and success in stream restoration projects. The most important objectives identified were those focusing on ecological improvement. Indicators of this were increases in water quality, chemistry, habitat, and biological diversity. These indicators are well accepted and used throughout projects to assess their ecological success.

This study co-opts Woolsey's objectives as they relate to water quality and in-stream habitat improvements. Furthermore, the goals and objectives outlined in the Willamette River Design Notebook provide a basis of understanding for this study.

These objectives guide decision-making, and intervention type and deployment throughout the previous diagrammatic efforts and subsequent case study.

From these sources, goals were defined using current ecological restoration metrics. My goals for the project were: 1) investigate methods for improving in-stream and connective habitat potential and quality, 2) investigate methods for improving water quality, and 3) investigate ways to improve public access and connectivity. These goals were identified as those most important for ecological performance and success of streams. Successful stream systems are those that house a variety of biological diversity, promote heterogeneity of channel and embankment conditions, aid in connecting to the large landscape matrix of patches and corridors, and resolve ecological, political, and economic interests. Additionally, long-term success relies on investment, pride, and care enabled through public access, visibility and connectivity. My objective in setting forth these goals is to project a catalogue of conceptual interventions for concretized streams. My hope is that such a catalogue might serve as a basis for future decision making in concretized situations.

To identify the primary techniques in traditional stream restoration a review of strategies currently in use was conducted. Traditional techniques are those well established in the stream restoration industry. These were sourced from the United States Department of Agriculture's (USDA) Natural Resource Conservation Service (NRCS) National Engineering Handbook Part 653: Stream Corridor Restoration (NEH-653) (United State of America, *Stream Corridor Restoration: Principles, Process, and Practices*) and the United States Army Corps of Engineers (USACE), Institute for Water

Resources (IWR) Management Measures Digital Library (MMDL) for Streams and Rivers (USACE-IWR Managment Measures Digital Library). These two agencies and the referenced documents promote and engage in water issues as they relate to safety, security, and restoration of water systems. The analysis highlighted how these techniques were effective, where they were typically used, and what they yielded. This review was supplemented by additional literature review as to their effectiveness in restoration projects. The traditional techniques were then categorized based on their ecological function and ability to meet the goals and objectives of the project (see Appendix A).

The goals and objectives of the project guided which techniques had greatest potential for application to a concretized channel. In a further effort to identify positive techniques for application in concretized streams, three case studies were reviewed in order to understand how interventions were developed and deployed within specific sites. These case studies were selected because they each addressed similar concerns within concretized streams albeit not fully the ecological capacity or performance. Case studies included the Willamette River in Portland, Oregon, John Todd's Canal Restorer, and the Los Angeles River in Los Angeles, California.

A matrix of traditional techniques was developed (see Appendix A). This matrix was intended to capture the most traditional stream restoration techniques and their effective use. One of the major sources was the NEH-653. Furthermore, these techniques have been deployed in projects throughout the country both by private entities and government agencies. These industry and governmentally accepted techniques provided the foundation for the matrix as well as an understanding of how each was used.

The handbook also provided information on placement, rigidity, effects, and tectonics. These techniques can be placed in two main categories: in-stream and streambank techniques. From here each techniques were broken down based on their effective use, where they were used, and what were typical results. Further investigation of the techniques provided new information about their effective use and deployment. For instance, in *Effects of stream restoration on ecosystem functioning: detritus retentiveness and decomposition*, stream restoration techniques like the insertion of in-stream boulders and woody debris illustrated that such strategies can successfully reverse heterotrophic and coarse particulate organic matter (CPOM) depletion. Thus, these techniques contribute to the efficient ecological functioning of impacted streams (Lepori, Palm, Malmqvist 2005) (see Appendix A).

Photos of each technique were sourced to better understand where each technique was used (deployed), what they looked like, and how they assembled. This method of information collection also led to understanding who was using and advocating for some techniques, i.e., lunker structures were developed in collaboration with trout fishing organizations to improve recreational opportunities as well. Further investigation through the USACE IWR MMDL for Streams and Rivers provided more in-depth information. This data reviewed all the current techniques acceptable by the USACE for ecological restoration projects. The MMDL also provided information on certain techniques' usefulness in specific conditions, installation standards, outputs (shading, nesting), stream morphology (grade of stream, width, bank slope), and inputs (costs, material, plants needed, concrete). This database was augmented by other allied organizations such as the US Environmental Protection Agency (USEPA), the NRCS among others. Few techniques dealt directly with conditions similar to concretized streams or bulkhead walls (vertical, steel encased walls).

Continued research on the various techniques was conducted through the review of various articles (see Appendix B). Several studies buttressed concepts put forward in the NEH-653. This was important to substantiate the effectiveness of several of the traditional techniques. Other research established that rigid in-stream and streambank interventions had negative effects on the long-term dynamics of the river. Although created to recreate desired river morphology, protect banks, provide habitat cover, increase vegetation, and manage stormwater these techniques created rigid channels with their structural integrity lasting around ten years. The rigidity of these structures did not allow them to respond to river dynamics. Current research suggests we should use fewer, better-designed techniques for maximum benefit (Thompson 2002).

From here, techniques were categorized based on their ecological function. The categories were based on both goals and objectives for this design project. Again, project objectives included improved water quality, increased in-stream habitat, and improved access and connectivity to population centers. In the process of categorization, some techniques were found to have little ecological value. Rip-rap, for instance, possesses little ecological value unless it is coupled with in-planting. In-planting is a strategy commonly seen in restoration as a bank stabilization measure. The rip-rap prevents lateral movement of the stream channel, similar to the concrete trapezoid channel. However, when submerged it does allow for sedimentation and therefore potential plant propagation and shelter for invertebrates and mammals alike. In-planting helped rip-rap edges to accommodate a broader range of functions while preventing erosion and lateral movement. This type of categorization made clearer the intention of some of these traditional stream restoration techniques.

The categorization provided conclusions as well. All of these techniques were either structural or natural in their composition. They either dealt with wooden support systems, steel mesh, and staking, or seeding, root-wad, and vegetation measures. These techniques were also designed for restoration projects with ample space and assumed that a naturalized condition was part of the project goal. It became apparent that these techniques would need to find new ways of working and expressing themselves if they were to function in more tightly constrained and/or armored sites.

After analysis, the highest potential techniques were collated into a master list. This master list informed a series of hybrid design interventions that could be deployed in concretized streams. This intervention catalog was developed as a visual/diagrammatic matrix that considered cover, in-stream, bank-type, connective, and other projective techniques to improve ecological performance of the stream. This initial catalog was used as the primary guide for a hypothetical design of the concretized portions of the lower Mill Creek Watershed in Cincinnati, Ohio. This portion of the project was intended to investigate how these interventions would interact, and potentially change when deployed within an actual site. Hypothetical interventions were deployed with the intent of positively affecting water quality, and in-stream habitat, and with an eye toward enhancing community access and connectivity.

The next step was to prepare a series of diagrams that looked at the techniques that aided in achieving the goals and objectives of this project. Within this study each applicable technique was considered in light of a concretized condition. A disciplinary approach was taken to vet ideas. The diagrams utilized the sectional information gathered from personal observation and topographic survey information. These hybrids explored ideas of canopy, floating structure, in-stream deflectors, combined-sewer capture, vacant land utilization, guerilla-style interventions, and animal condos among others. Each hybrid was then linked back to the traditional techniques that provided its basis in order to help frame the reason and function for each hybrid intervention. This provided better clarity to the hybrid. Intentions of each hybrid were also outlined based on the traditional techniques used in each hybrid. For instance, a canopy structure with hanging plant material acted similarly to the traditional technique of tree cover along riparian corridors. Additionally, by anchoring vegetated mats or trellises within a vertical channel section we might mimic the effects that live stakes, in-stream tree cover, brush mattresses and lunker structures have on a traditional restoration project (see Figures 5, 6 and 7, and Appendix C for additional techniques). In many of these concretized conditions, riparian zones do not exist. Therefore, an artificial canopy might be deployed in regulating stream temperatures, and providing organic matter through suspended plant material and cover for a variety of animals – just as tree cover does along natural riparian corridor. This technique could be deployed in areas in order to provide greater habitat connections to the larger landscape matrix. This approach was repeated for all the hybrids.

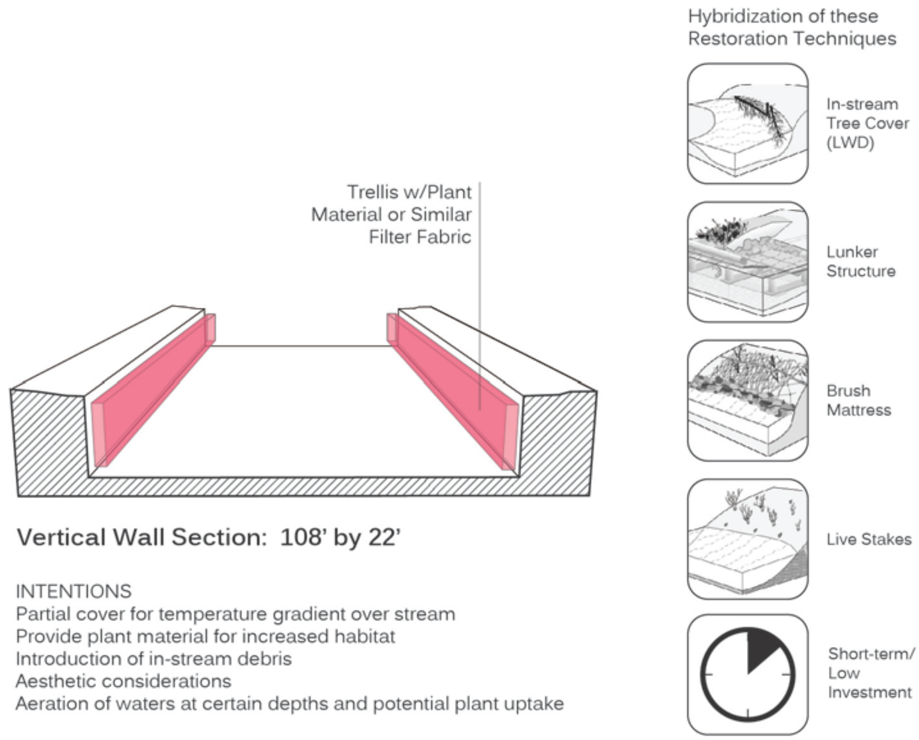


Figure 5. Hybrid Technique Diagram

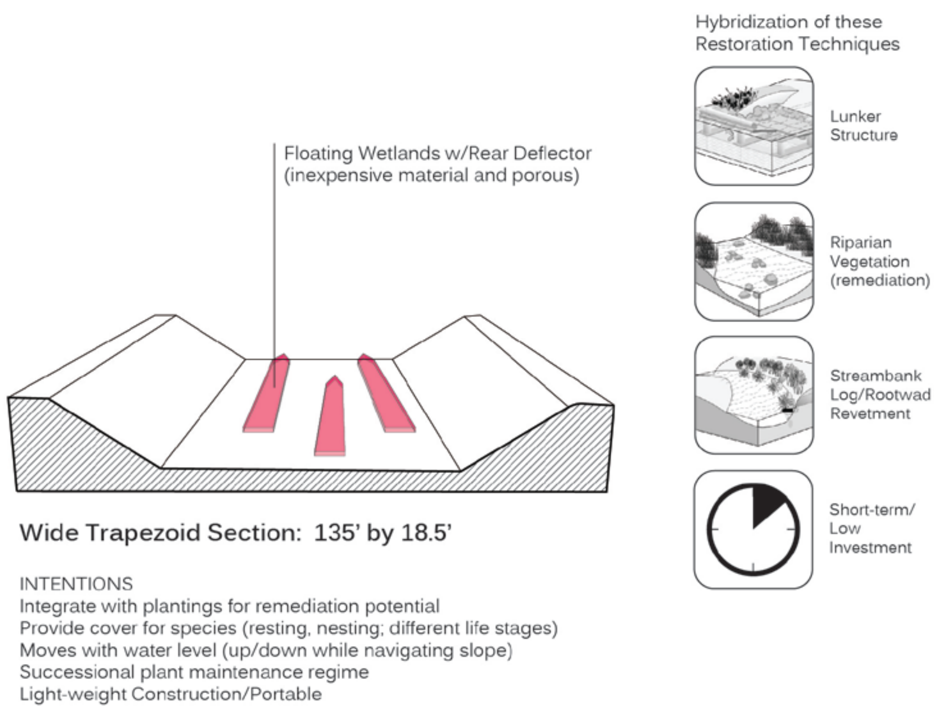


Figure 6. Hybrid Technique Diagram

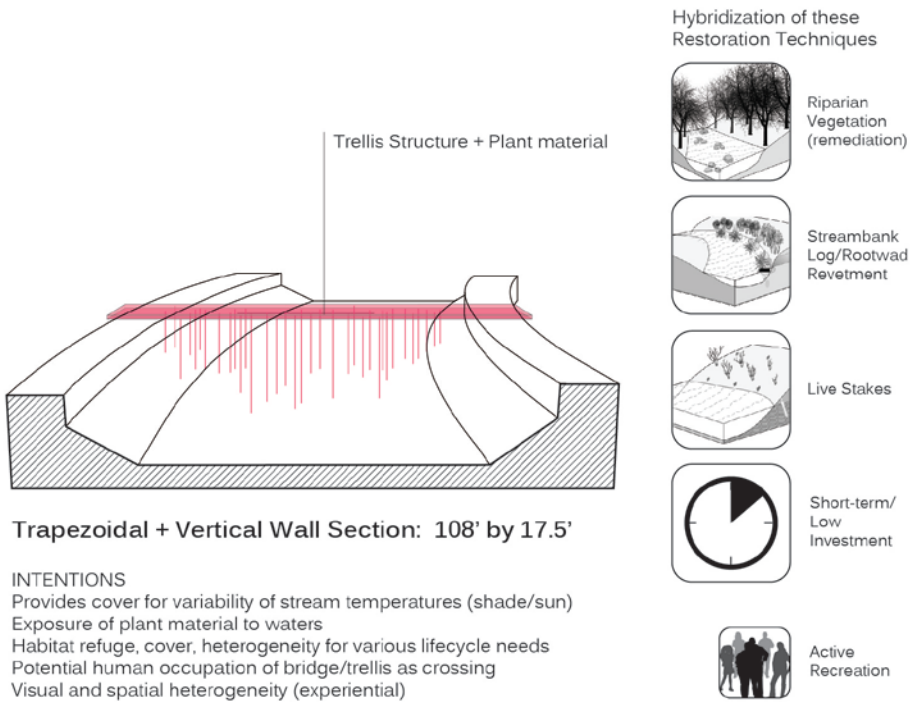


Figure 7. Hybrid Technique Diagram

The movement back and forth from diagram to traditional technique and linking the new hybrids to the traditional techniques allowed for a better argument for each new intervention type. This process of iteration and adaptation augmented by case study review yielded over thirty hybrid techniques for use in these concretized streams—an intervention catalog (see Figure 8). To resolve these questions, sectional and three-dimensional studies were completed to investigate and understand how spatial and biophysical interventions could be accommodated within different concretized stream conditions—trapezoidal, vertical wall, crib wall and so forth. Working back and forth, from intervention catalog to site conditions informed the new intervention types as well as strategies—long-term and short, high-value and low.

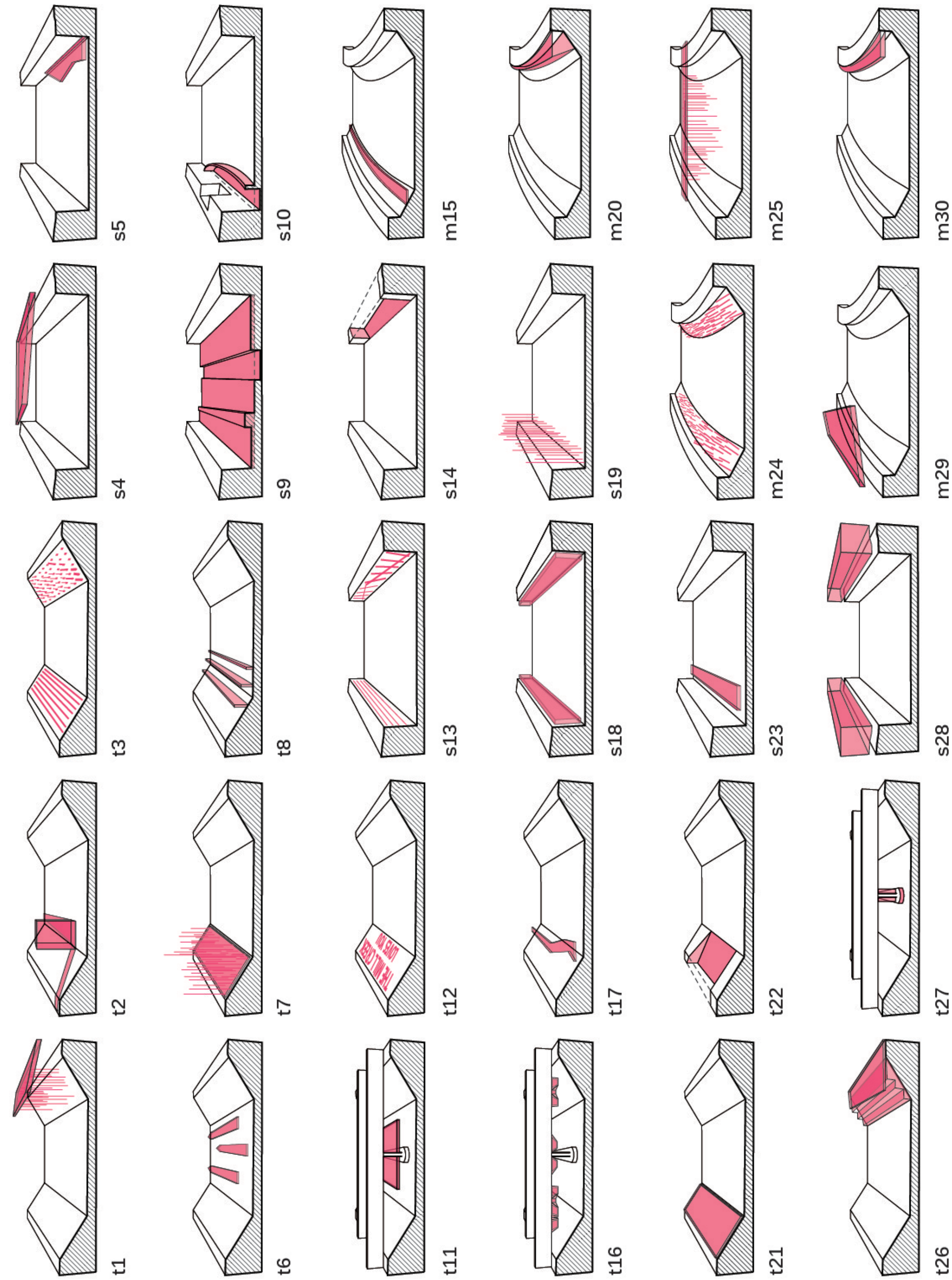


Figure 8. Intervention Catalog

Chapter 4: Methodology II – Site Identification and Analysis

"The Mill Creek is an asset to our region, conveying a unique sense of place. Along its 28-mile length, you can enjoy scenic views, historic structure and wildlife, including soft-shelled turtles and black-crowned night herons."

- Bruce "Commodore" Kohler (2011)

Rationale for Case Study

A case study approach allows for further investigation of design interventions as they relate to a specific context, place, and existing conditions. The Mill Creek, in Cincinnati, Ohio fulfilled that role in this project. Portions of the Mill Creek fell victim to concretization in the 1980's by the USACE. Targeting the safety of highly industrialized and valued properties, many of the concrete-lined channels reside in the Lower Mill Creek (LMC)—river mile zero (at the Ohio River) to eight (north near Ivorydale). These modifications have prevented major flooding and saved millions of dollars of property from succumbing to flood damage. However, these sections lack biodiversity, channel heterogeneity, and perhaps more importantly a vision for what they can become.

The Mill Creek Design Case Study began with an analysis of existing stream corridor and contextual conditions, current restoration projects, and edge conditions. From this analysis criteria were developed for initially deploying the catalogue of hybrid interventions. Given the goals and objectives of this study, I asked: what conditions are best for locating these new hybrid interventions? Where does the greatest ecological/

stream restoration potential exist? And, where are the opportunities for community connection and access?

Cincinnati's Mill Creek: An Unnatural History

The Mill Creek has seen better days. Since the establishment of Losantiville (the original name of the City of Cincinnati) and a number of stations up the Makatewa Valley the Mill Creek Valley had been mined and exploited. Christopher Gist, a British explorer noted in 1751 that, "[the Mill Creek Valley] wants nothing but cultivation to make it a most delightful country" (p.9). With these and other images in mind, the marketing strategy became clear. John Cleves Symmes strategically changed the valley's name to Mill Creek to signify to settlers the potentials for manufacturing and processing industries – flour, grist, and other mill-type operations. The taking of indigenous peoples' land and exploitation of resources in the valley began as early as the 1750's with military support sent to Losantiville to claim lands and protect new industries. From this point on, the Mill Creek would bare the brunt of European settlement as they built communities, cultivated lands, and processed goods for the community and export (Hedeen 1994).

Throughout the next two centuries important industries such as breweries, soap and chemical plants, slaughterhouses, stockyards, and mill's lined much of the Mill Creek. The constant dumping of wastes in to the Creek and out to the Ohio River made for miserable conditions. Additionally, utilization of the Mill Creek as a source of industrial process water taxed the environment even more. A water report from 1913 showed that the daily water usage for the fifteen slaughter and pack firms in the Mill

Creek Valley totaled 311,000 gallons of domestic water, 12,000 gallons of well water, and an additional 425,000 gallons of canal water for operations. 748,000 gallons of heated, polluted, wretched, and bloody water issued into the Mill Creek daily. Rinse water from wool-carding process plants also entered the Mill Creek. This bloody, dirty rinse together with spent lime constituted a "foul-smelling greenish black liquid with heavy sediment. The sum of effluent volumes recorded […] discloses that each liquid gallon flowing from the Mill Creek's mouth in 1913 contained a cup of warm swill contributed by thirty-six alcohol, meat, and animal by-product firms" (Hedeen 1994).

Additionally, the Valley served as the major transportation route out of the Cincinnati basin. The steady slopes allowed for ease of navigation. From 1825 to 1845 the Miami-Erie Canal was constructed in an attempt to provide transportation of goods from the Ohio River at Cincinnati up to Lake Erie at Toledo. This system ascended over 500 feet at its peak in northeastern Ohio through a series of locks. With this innovation, businesses could use the canal for transport of goods and access to new markets. This major engineering feat was soon dwarfed by steam-horses. As the rail industry enlarged it followed similar routes to increase efficiencies. With these technological advances, new industrial centers (like Lockland, some 14 miles north of the City) challenged the city's industries as some began to leave for higher ground. As development within the Mill Creek Valley increased, its lush forests began to fall, natural floodways altered, and edges filled with rubble and debris. With this drastic change in land cover, habitats were severely altered and populations of both fish and birds decreased. The bountiful hunting ground described by Symmes was reduced to a barren, lifeless landscape. Change in surface cover also contributed to increased flood events. Floods throughout the 19th and 20th centuries destroyed millions of homes and cost cities millions of dollars to restore and rebuild. These events built upon the Flood Control Act of 1917—early legislation following major floods in the Mississippi and Ohio River valleys enacted to control flooding and protect high value land. Events shortly thereafter, most notably the flood of 1937, which reached a height of 80 feet, caused $17.6 million in damage and solidified the reasoning and need for further flood control and prevention. At the time the American Red Cross considered this disaster the second most costly in U.S. history, only slightly less costly than World War I. Additionally, these policies and changes put in place district regulatory bodies throughout the Country with the sole purpose of flood control (Hedeen 1994).

In the years following the 1937 flood, legislation and flood control measures were passed with profound public support. The Flood Control Act of 1937 authorized the United States Army Corp of Engineers (USACE) to study and propose flood control measures across the country. Some $178 million was appropriated in 1937 and 1938 for projects that would help with flood control (Hedeen 1994). USACE would become the authority and regulatory body through which study and plans for the Mill Creek waterway would flow.

Through the middle of the century flood control dams were built on the Mill Creek (the Great Barrier Dam at the Ohio River), along with channelization and concretized amendments. The studies completed by USACE showed the advantages of lining the Creek with concrete in several locations.

> "The Corps also conducted a study of a much larger channelization program stretching from the barrier dam north through Reading. This $8 million dollar project would eliminate flood damage over a greater area and thus produce annual benefit of $54,300" (Hedeen 1994).

Although the recommendations from this study were not fully realized, portions of the Creek were encased in concrete, fitted with crib walls, edges stabilized with rip-rap, and its edges were re-graded to retain profitable land and businesses within the City. This effort commenced in 1981 with the first of several phases of channelization of the creek in order to enhance flood control around highly valued sections—the industrial headquarters of Proctor and Gamble and major infrastructures (Interstate 75) near St. Bernard.

Although flood control was deemed successful to the ACE and adjacent land owners the effluent and quality of life within the Creek was still in disarray. With the passing of the Clean Water Act in 1972, cities had to react to pollution control regulations. Plans were made to separate both storm and sewage effluent at a cost of $1 billion over the next fifty to seventy-five years for the Mill Creek.

Current Restoration Efforts in the Mill Creek

Today, the Metropolitan Sewer District (MSD), Hamilton County and the City of Cincinnati's sanitary and storm systems managers, has been mandated to respond to the Federal EPA's Consent Decree to eliminate combined sewer overflows by "85% of the 14 billion gallons of combined sewer overflows (CSOs) and eliminate all sanitary sewer overflows (SSOs), about 100 million gallons" (What's the Problem?). The Consent

Decree put forth regulations intended to control the volume of water making its way downstream (decreasing downstream flood and effluent issues). This has pushed the county and city to find new ways of handling increased volumes and pollution of water bodies. Organizations such as the Mill Creek Restoration Project (now Groundwork Cincinnati) have been working for decades on restoring sections of the Mill Creek. Establishment of a trail/greenway has been the organizations biggest success and ongoing project.

Additionally, The Mill Creek Watershed Council of Communities has been working on the Mill Creek for decades. It has mainly focused upstream in the suburban areas of Hamilton and Butler County. Many communities have made progress on some of the Creek's tributaries by restoring several of them to a naturalized condition. Additionally, bio-swales, rain gardens, and other green infrastructure projects are being supported and implemented by the MSD in partnership with communities, park agencies, and the aforementioned Mill Creek advocacy organizations. Despite this progress, some regulatory bodies are unwilling to work with communities, officials, and other stakeholders on restoration attempts in the lower portions of the creek. Also, new wastewater treatment plants in the Valley have greatly increased water quality and with it, biodiversity. Sadly, all of this progress disappears when the water of the Mill Creek reach the lower portion of the watershed (Hedeen 1994).

The fight for a clean and restored Mill Creek continues. The Mill Creek Yacht Club, an advocate for recreation and environmental stewardship, holds clean-up events and kayaks the Creek every month to keep eyes on it (see Figure 9).

Figure 9. Paddling the Creek (Kordenbrock, 2012)

The Army Corps of Engineers is considering a new study of the watershed including the terrestrial and riparian projects that have helped with water quality and volume discharges into the Mill Creek. Additionally, the Mill Creek Watershed Action Plan (WAP) has become the guiding document that local organizations, public agencies, and advocacy groups' reference for the improvement of the Mill Creek. With this plan, endorsed by both the OEPA and Ohio Department of Natural Resources (ODNR), funds can be leveraged through state and federal agencies. Still, project priority is placed on the Upper Mill Creek. This working document has identified key projects for the restoration of the Mill Creek, all within the Upper Mill Creek.

Efforts to address the Lower Mill Creek watershed have been in the works for several years. The Ohio-Kentucky-Indiana Regional Council of Governments has been working on the Lower Mill Creek Action Plan along with members from the City Parks Department, University of Cincinnati, and the MSD to improve waters within the most severely degraded portions of the Creek. A recently completed draft of the Lower Mill Creek Watershed Action Plan (LMWAP) has included an extensive inventory, analysis, and understanding of the Lower Mill Creek (Lower Mill Creek Watershed Action Plan). This targeted effort will allow the Committee and its endorsees to source funds for the clean-up, restoration, and further study of the Mill Creek.

Site Selection

A previously developed network was utilized to begin interviews with key constituents. A kayak trip of the Lower Mill Creek with scientists and watershed planners proved to be the most resourceful (see Figures 10 and 11). Conversations as well as reports, GIS data, and other resources were synthesized from these individuals. The reports focused on both the larger Mill Creek Watershed as well as the Upper and Lower portions.

Figure 10. Mill Creek

Figure 11. Mill Creek

However, the resources available for the Lower Mill Creek were less developed. Watershed Action Plans for the Upper Mill Creek had been in development for several years. Restoration of waters in this area had funds, and state and local support (see Figure 12).

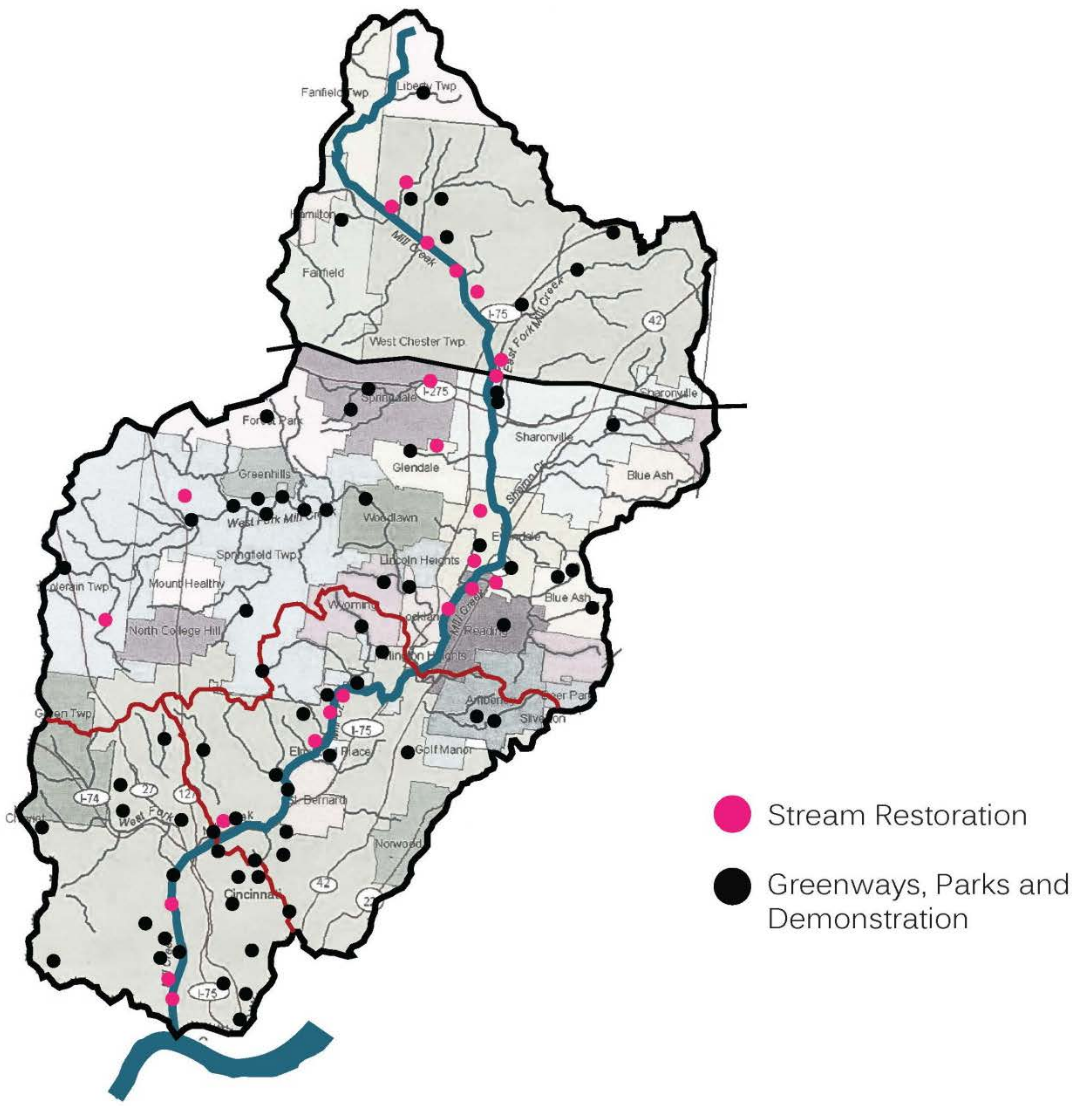


Figure 12. Current Watershed Projects

Concerted efforts and much investment in restoration were focused in the Upper Mill Creek. How could we bring to light the importance of the Lower Mill Creek? A Watershed Action Plan was in development for the Lower Mill Creek. However, little attention was being paid to the most severely degraded portions—those concretized. Based on the goal of this project it made my decision to engage the Lower Mill Creek easier. This area had the only concretized portions of the creek and also the worst IBI and QHEI scores. It was also home to two Superfund sites as well as 36 of the 39 combined sewer outfalls in the Lower Mill Creek (see Figure 13).

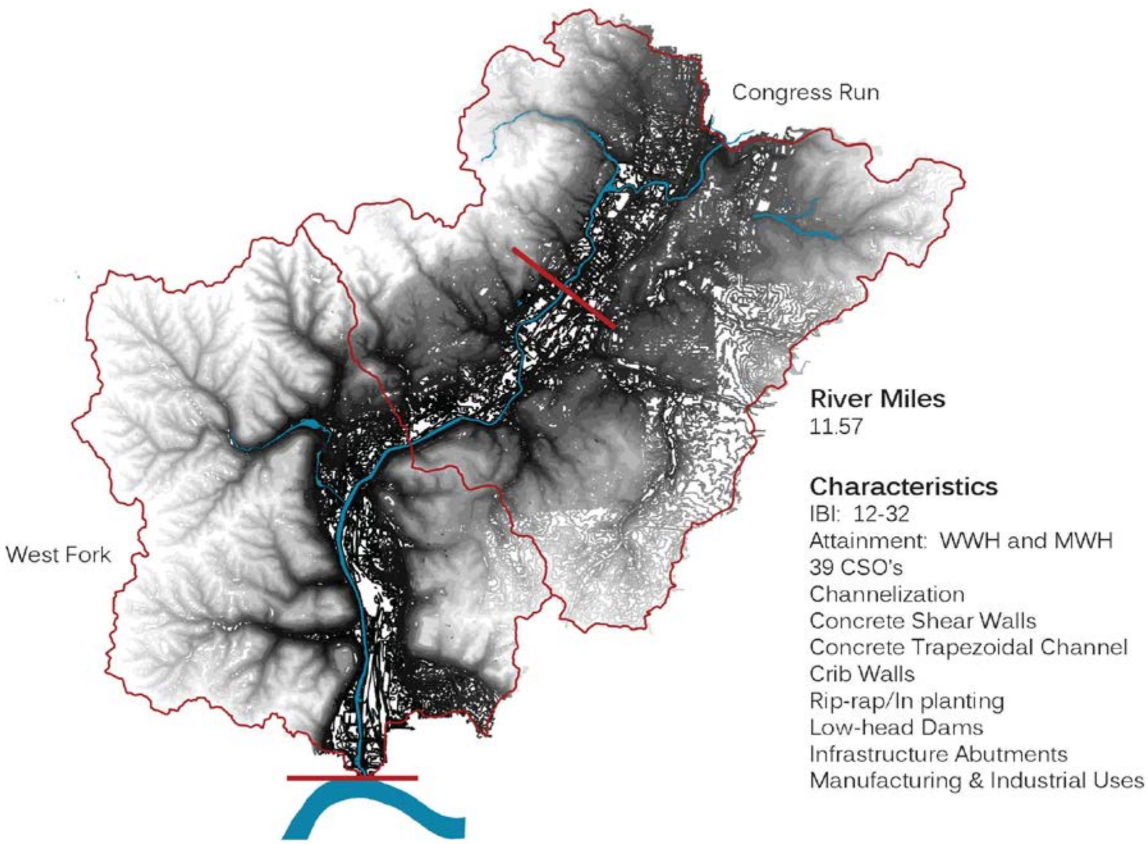


Figure 13. Lower Mill Creek Watersheds

The Lower Mill Creek had already been through analysis by local organizations. Understanding the current situation was key to developing both the argument for engaging concretized sections as well as being able to jump in to design efforts and site specific analysis. However, analysis of current park and greenway systems was analyzed. It became clear that a fragmented park and vegetation matrix proliferated the Lower Mill Creek Valley, especially in the concretized sections. This revelation created a more substantial argument for intervening in concretized sections.

As previously noted the Lower Mill Creek is highly industrialized and has been the site of massive infrastructural projects because the Mill Creek Valley provided easily navigable slopes to the north from the Ohio River. The Lower Mill Creek exhibits very low biological diversity. A 2011 water quality report showed an Index of Biological Integrity (IBI) ranging from 12 to 28. This range is low; IBI scores can range from 12 (indicating the lowest level of diversity) to 60 (indicating the highest level of diversity). Over its length, the Lower Mill Creek (LMC) is designated a Modified Warm-water Habitat indicating that its diversity is low and interaction with this water is highly discouraged (Midwest Biological Institute 2012). Infrastructural crossings in the form of bridge abutments and dams populate almost every mile of the LMC (see Figure 14).

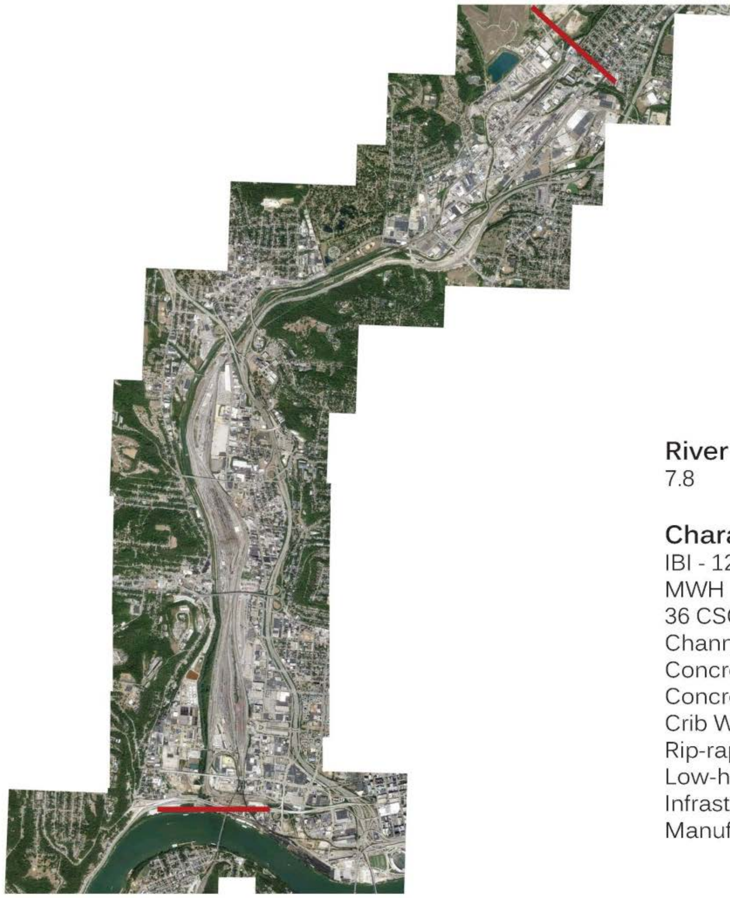


Figure 14. Lower Mill Creek Aerial

In an effort to identify more specific focus areas a set of site criteria was developed to aid in locating sites for deploying the hybrids of the intervention catalog. The criteria considered five points for potential intervention: 1) portions of the creek that are devoid of life—providing the most difficult design challenges, 2) spatial juxtapositions—those that exhibited stark contrasts in form and scale, 3) highly industrialized contexts, 4) areas where contextual opportunities could be taken advantage of—access points out of creek, and visual connections, and 5) sites that were typologically abundant throughout the creek and therefore broadly applicable. These five points were predicated on personal observations as well as the ability to highlight key moments along the Creek. These efforts also appeared to exhibit the highest level of opportunity for design interventions and therefore would create a more robust and diverse intervention catalog.

Focus areas were then identified based on five criteria: portions of stream devoid of life, spatial juxtapositions, typologically abundant, highly industrialized, and contextual opportunities (physical, psychological, and visual). Based on both personal observation and aerial analysis two sections along the Lower Mill Creek were identified; Section 4A (Ivorydale/Proctor and Gamble), and Section 3 (St. Bernard) (see Figure 15). The numerical values, or names, of these sections refer to the USACE's project sections during the flood control prevention design and construction throughout the 1980's.

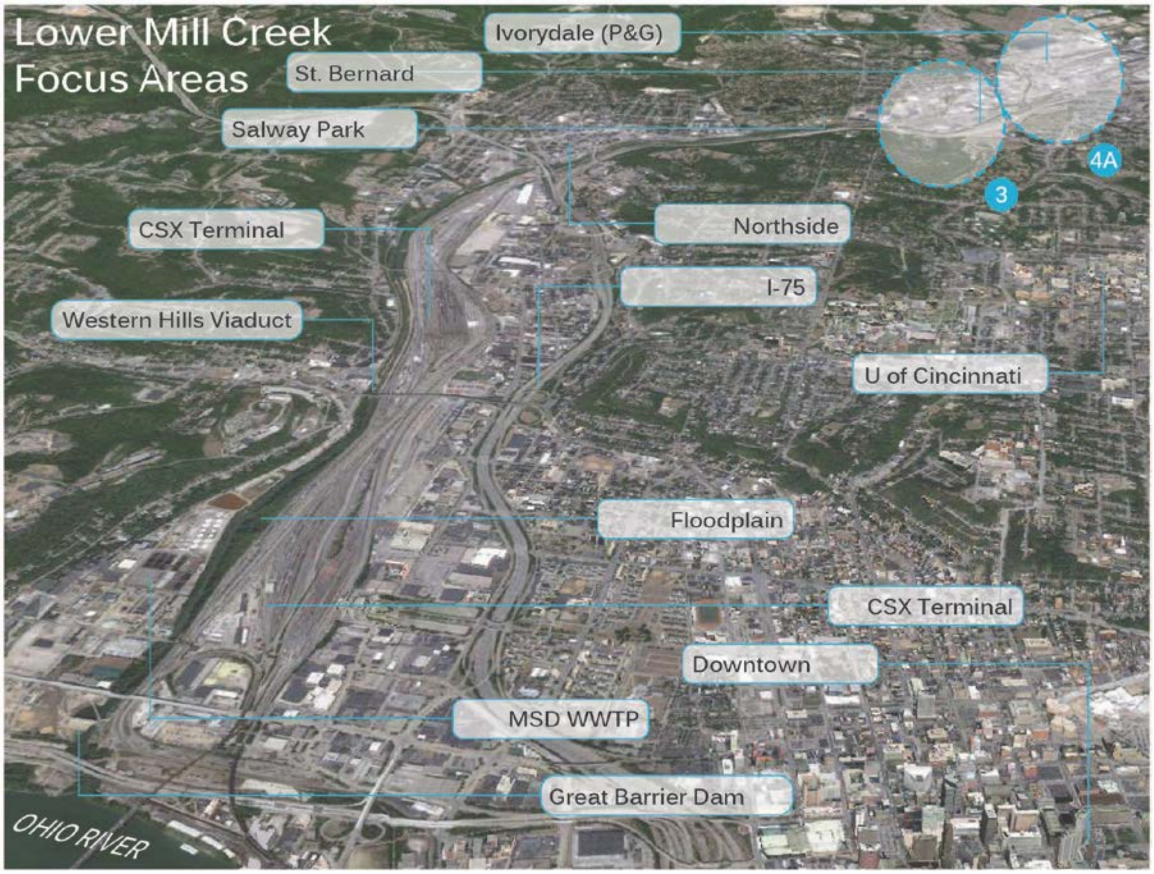


Figure 15. Focus Areas

Geographic Information System (GIS) data was obtained from the City of Cincinnati Parks and Recreation Department and existing conditions were analyzed to find the best situations in which to intervene. This data included parcels, streets, open space, land cover, water systems, and utilities among others. This data coupled with aerial imagery helped to clarify why these Sections were ideal for interventions. Mapping of the existing park network quickly identified a lack of open space in the Lower Mill Creek study area; especially those areas directly adjacent to the Mill Creek (see Figure 16).

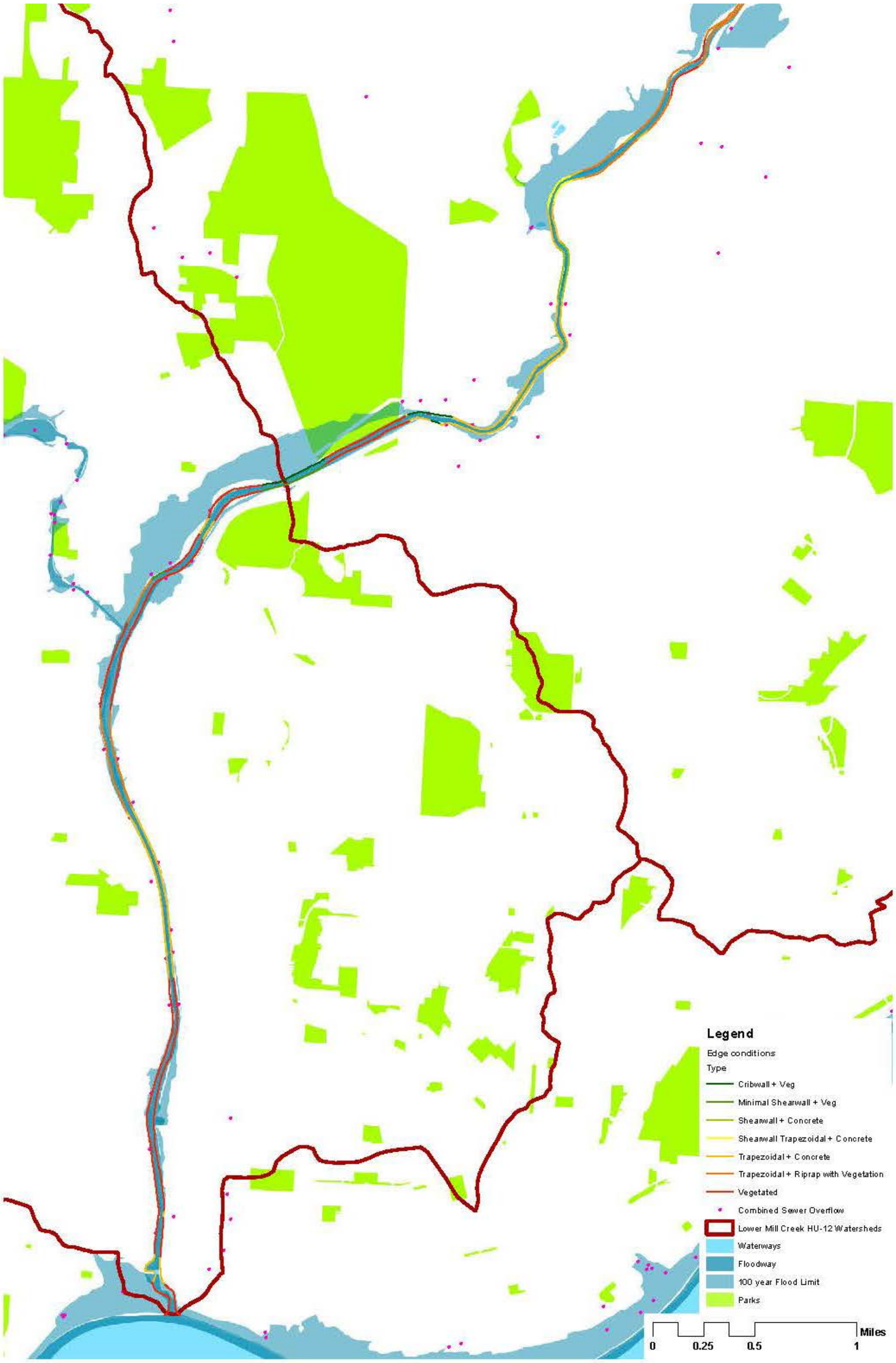


Figure 16. Existing Park Map

Furthermore, an edge analysis was conducted and mapped via GIS. These conditions were broken down into six categories or found conditions along the Lower Mill Creek: cribwall with vegetation, minimal shearwall with vegetation, concrete shearwall, concrete miniature wall and trapezoid, concrete trapezoid, rip-rap trapezoid with vegetation, and complete vegetated/unimproved. This analysis found that 36 percent of the Lower Mill Creek was concretized. Typologically abundant, the concretized sections, especially the concrete trapezoid (31%), would be key areas to intervene (see Figure 17). Additionally, these areas are largely devoid of life unless emergent plants have found holes or crevasses to reside in. These areas were also highly visible from local transportation corridors, the ones they were protecting.

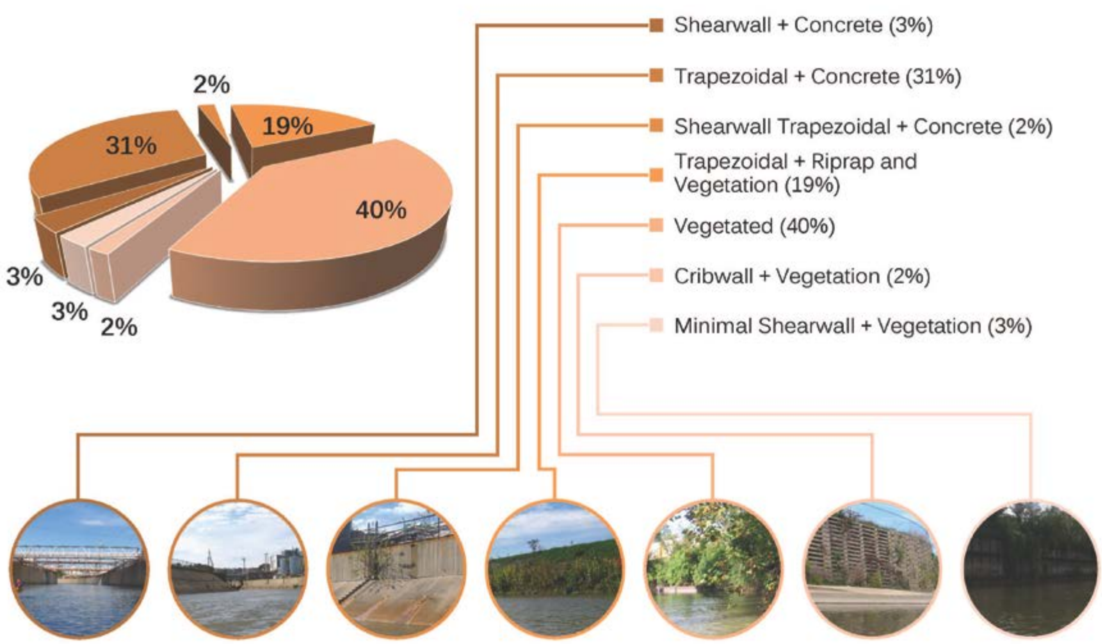


Figure 17. Edge Conditions of Lower Mill Creek

Sections 4A and 3 were analyzed in order to understand their conditions, anomalies, land uses, hydrology, existing vegetation, opportunity parcels, views, current infrastructure and potential access points. This analysis allowed decisions to be made about where to locate access points, in-stream, streambank, and infrastructural interventions. Sectional and planimetric as-built information was obtained from the USACE Louisville Office. Hybrid techniques were deployed and designed into these existing sections in order to understand how they connected, performed, or needed to be adjusted. Working within this sectional mode I found that new intervention types were needed. By reengaging the hybrid diagrams, I found that new hybrids were needed as new conditions and sections were designed.

In Section 4A we find Ivorydale, the home of Proctor and Gamble, a Fortune 500 company and major employer in the Cincinnati Metropolitan Area. This industrial campus is still active and currently produces household cooking products. Based on both personal observation and aerial imagery the tops of channels are heavily packed with industrial buildings, silos, piping infrastructure, and rail lines creating a spatially interesting and infrastructurally rich context. This area is devoid of life. There is a weak riparian corridor or in-stream biodiversity throughout much of this Section. The only plant and animal life resides in storm drain outlets that have filled with sediment over time. This trapped sediment has allowed a number of novel ecologies to spring up in this portion of the creek (see Figure 18).

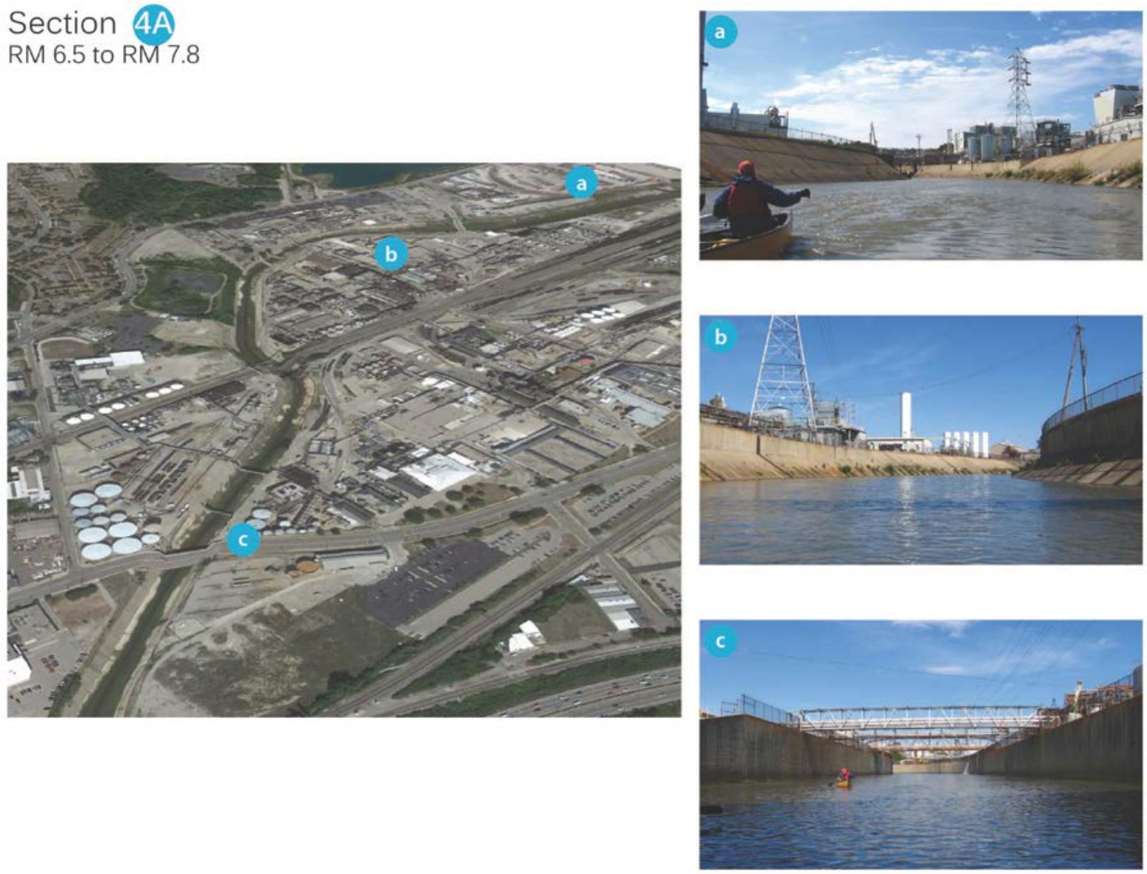


Figure 18. Section 4A Focus Area

This enriched the argument and objectives for creating a robust ecological corridor for both recreation and ecological function. Additionally, edge conditions were analyzed in order to understand the make-up of this section. Three types of concrete channels are found within this section—concrete trapezoid, concrete vertical wall, and a concrete hybrid of these two (see Figure 19).

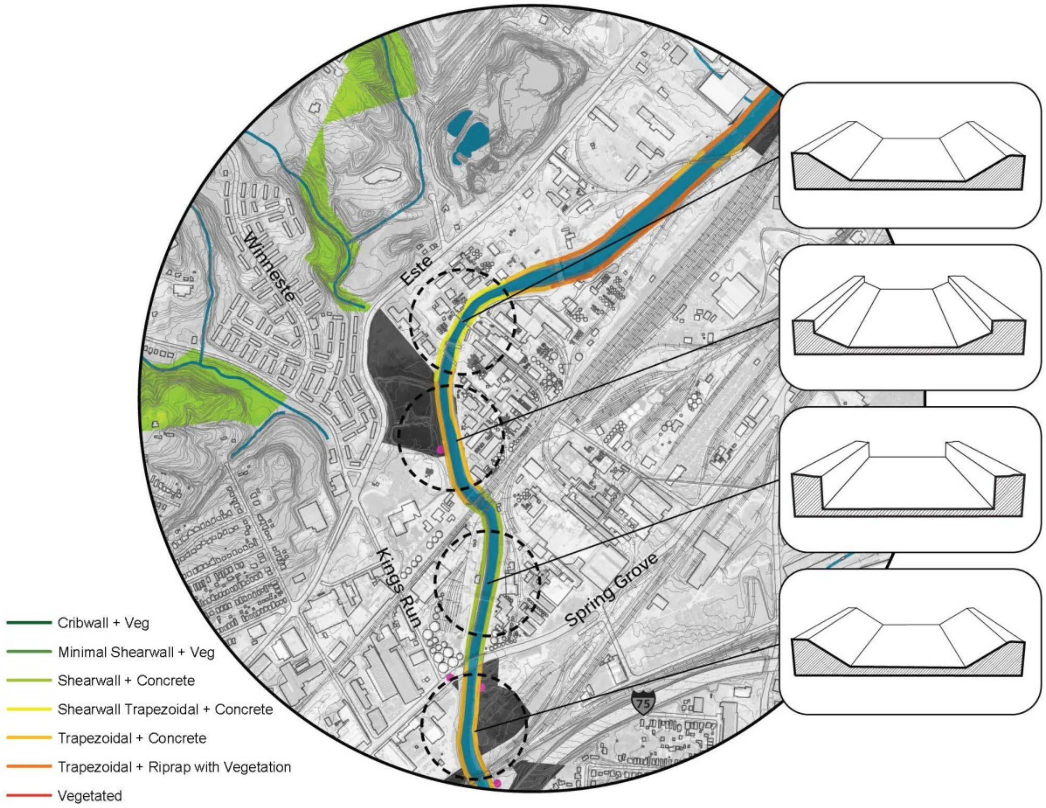


Figure 19. Edge Conditions in Section 4A

This section of the river experiences over ten infrastructure crossings. These take the form of roads, utilities, and rail. As a result this portion of the river also contains numerous abutments within the channel as well as a host of other support structures which reside within the channel right-of-way. These create multiple opportunities for interventions to play out within the stream channel. The presence of so much infrastructure also opened up discussion of other hybrid types, thus creating a more robust and inclusive intervention catalog. Continued analysis of opportunity parcels, those that are vacant, public, or educational/institutional uses, found that a large parcel could be engaged and utilized as part of the interventions for Section 4A (see Figure 20).

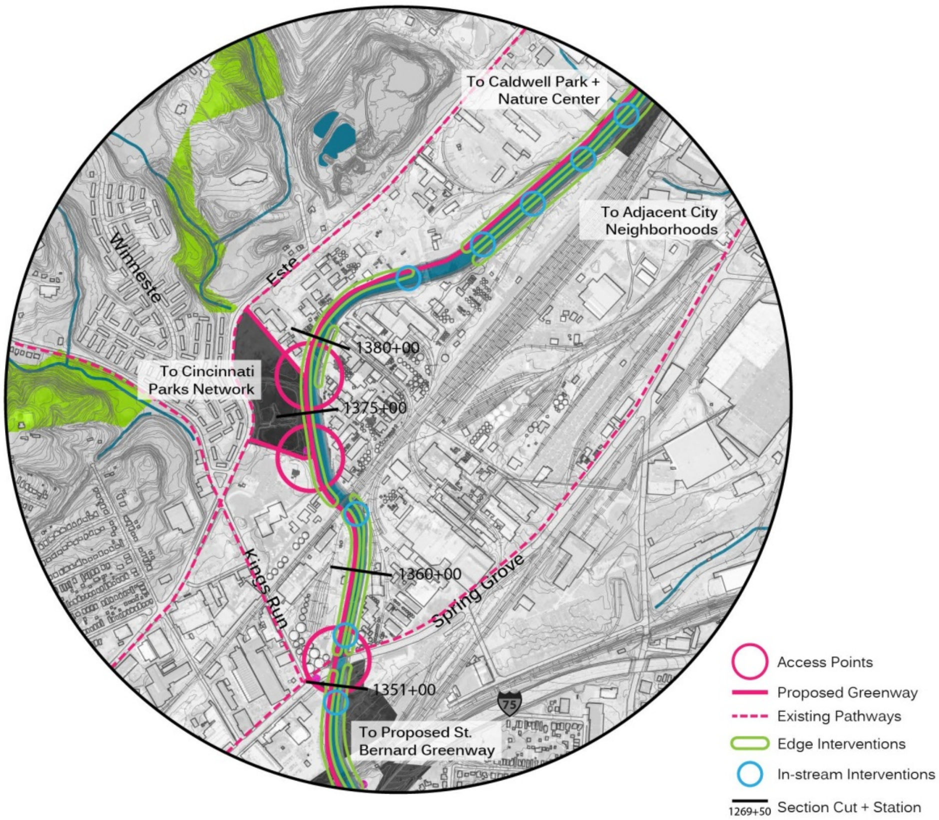


Figure 20. Analysis and Interventions

In Section 3 we find similarities, but the context is much different. Here, the views, spatial condition, and uses are very different—they are open, visually accessible and prominent as they hug highly-trafficked freeways and arterials. However, the channel is composed mostly of the concrete trapezoid, constituting 90% of its edge condition. Similar to Section 4A it too has little biodiversity save for a more robust riparian corridor along its margins.

Again, GIS data was analyzed in order to understand existing conditions and potentials. This Section was found to have many more connective opportunities. Salway Park, one of the only public parks abutting the Mill Creek, resides in this section (see Figures 21 and 22).

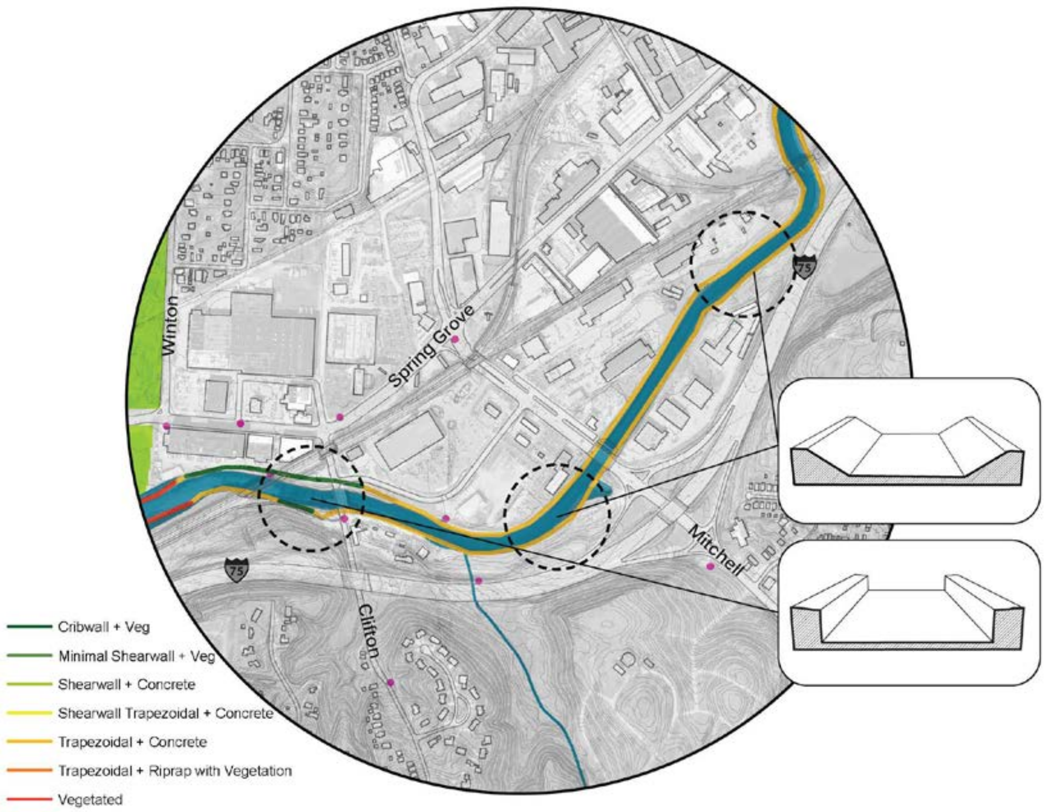


Figure 21. Edge Conditions in Section 3

It is also home to a major access point to the Mill Creek Greenway, a path envisioned to run the length of the Mill Creek for recreation and connective use. This site provided a key linkage within the focus area and was utilized as such. Infrastructure crossings, albeit less in number, were very prominent. These crossings are Mitchell Avenue and

Clifton Avenue, two major arterials coming from neighboring residential areas. These connections have potential for visitors and residents of surrounding areas to connect to the proposed Mill Creek Greenway (see Figure 22).

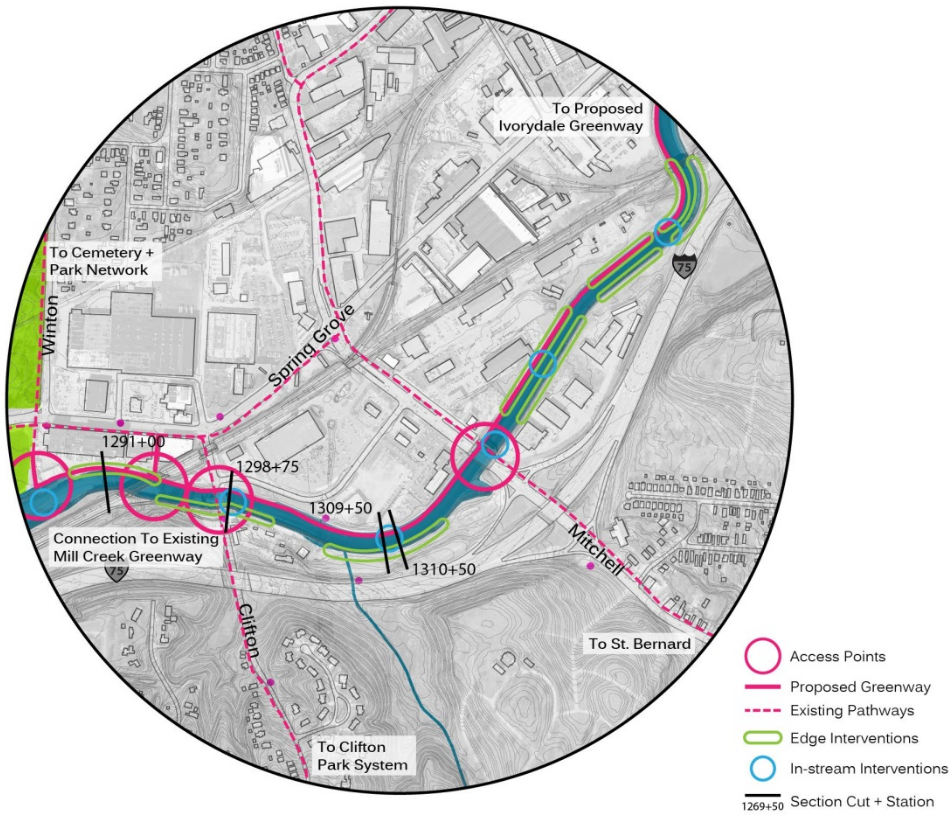


Figure 22. Analysis and Interventions

Section 3 is highly visible from Interstate 75. Trips along the creek as well as frequent travel on this highway identified key visual connections into the Mill Creek. Utilizing these view corridors became crucial to identifying where interventions would take place for both ecological benefit and as a visual cue to the Mill Creek's re-development, an indication to viewers that there is something happening here. The potentials for signifying the presence of Mill Creek become very important in this focus area. Both Section 4A and 3 were investigated through sectional and perspective drawings. This effort allowed a better understanding of how the hybrid types could be utilized in various conditions throughout each Section. This exploration also informed and added new hybrids to the interventions catalog or allowed for more refined resolution of previous hybrids.

Hybrid Deployment and Design Iterations

As part of understanding how each hybrid intervention would work, I conducted a series of iterative sectional studies. These drawings reference the intervention catalog, but also helped develop it. Sectional studies allowed multiple conditions to be designed and explored. They also allowed for an increased understanding of how certain hybrid interventions would react or adapt in certain conditions. The sectional studies were also used in order to refine details of how each hybrid intervention would interface with one another. This study also led to the understanding that certain hybrids could not be deployed or had to be thought about in different ways in order for them to be used in certain conditions—again, leading to new or refined hybrid interventions.

The sectional studies were also important in showing the dynamics of the Mill Creek. Normal flow and 100-year flood elevations were used in every section to show how the hybrid types would work with water dynamics. These sections helped develop new strategies for some of the hybrid intervention types related to their materiality, longevity, and use. In understanding the force and stress the stream would place on some of these hybrids, some were envisioned to fail or break-away. This decision prompted me to question material choices and connections or intentional disconnections.

The project then moved into rendered images that provided more detail on what hybrids looked like, how they functioned, and how they were deployed. This approach opened up several questions about tectonics, management, adaptability, and materiality. Moving between sectional study and rendering allowed these drawings to inform one another. Design choices began to change and take on new features. The renderings also capitalized on the layering of several hybrids— creating a hyper-ecological machine. Renderings enabled me to situate myself within the space and to make design decisions from the point of view of a potential user. Renderings are intended as seductive, but sublime at the same time, acknowledging these sites industrial character while making the site accessible to potential viewers.

Perspective drawings were then utilized in both sketch and detailed model formats. These renderings collapsed hybrid interventions into one drawing as a way to visualize, more clearly, what these areas would look like. These renderings allowed design choices to be made and materiality investigated. They also allowed for better visualization of what these hybrid techniques might look like. My goal was to evoke a specific sense of place through certain design decisions. These drawings solicited many new challenges as materiality, function, longevity, aesthetics, and maintenance were all questioned

Chapter 5: Project Outcomes

This project has explored design interventions at the diagrammatic level linking traditional techniques with new hybrids. This catalog provides a variety of intervention types ranging from short-term guerrilla-style to long-term interventions that require major modifications or a high level of investment. The hybrid catalog currently projects 30 hybrids intended to improve ecological conditions through water quality and in-stream habitat improvements. These hybrids also introduce the human element as part of longer-term strategies of accessibility and community buy-in (see Figure 8).

Sectional studies allowed for greater resolution of the hybrid catalog. It used the case study and its current sectional conditions to vet the concepts throughout the hybrid catalog. It prompted questions about connections and materiality. This investigation led to new hybrids as new conditions within the concretized stream were engaged. This added robustness to the hybrid catalog. Additionally, sectional studies allowed for investigation and consideration of water levels. Water systems are dynamic. Thus, they need to be considered in various conditions—depth of pool, flow characteristics, and relationship to edges and infrastructures. These considerations not only prompted questions about longevity, materiality, break-away tolerances, stress on objects, and permanence, but also how these elements ebb and flow with river dynamics (see Figures 23 through 28).

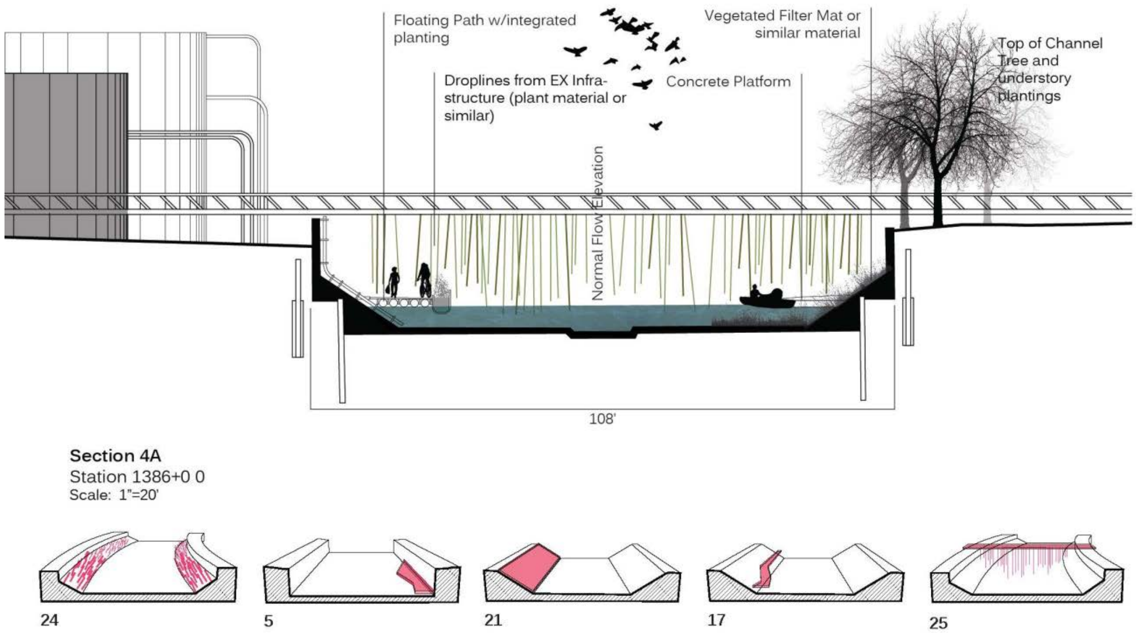


Figure 23. Section

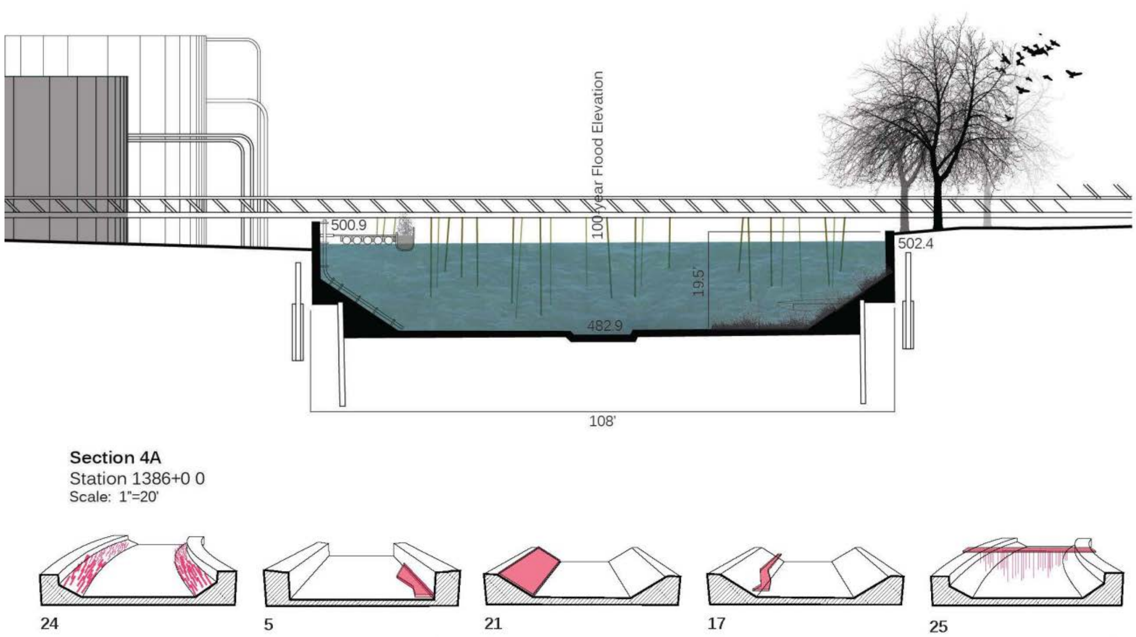


Figure 24. Section

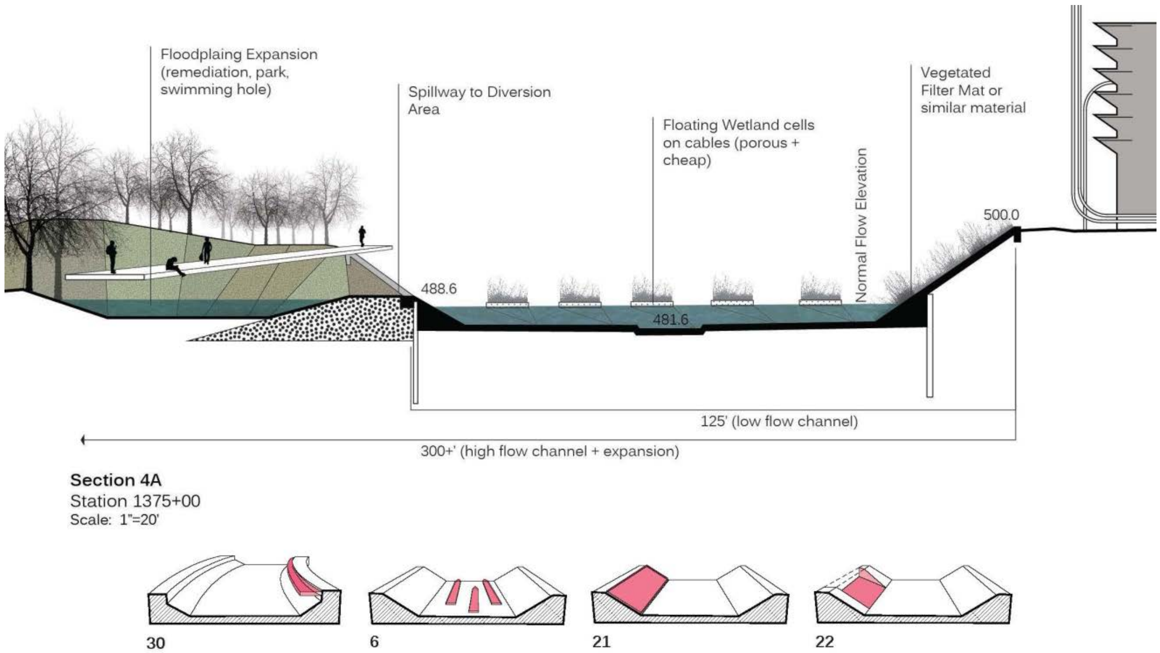


Figure 25. Section

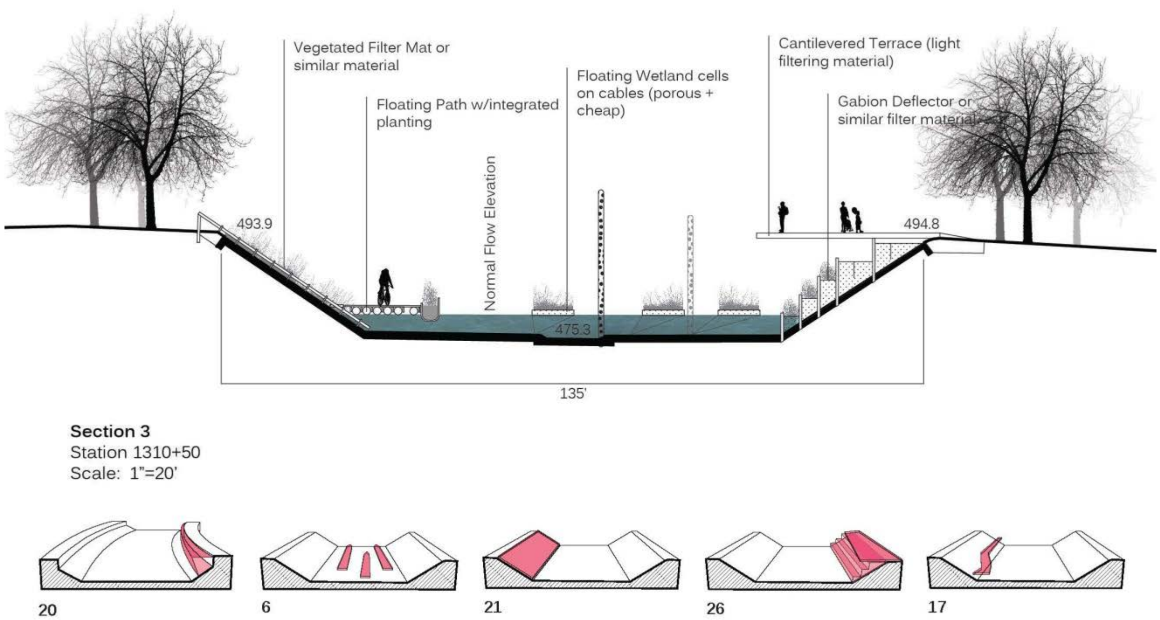


Figure 26. Section

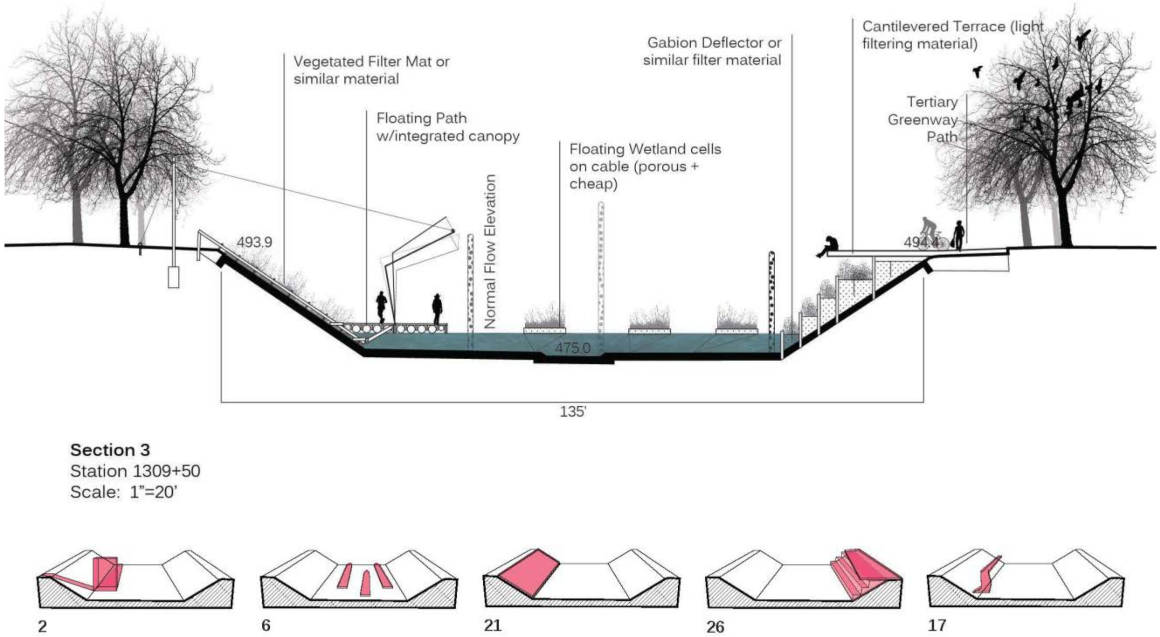


Figure 27. Section

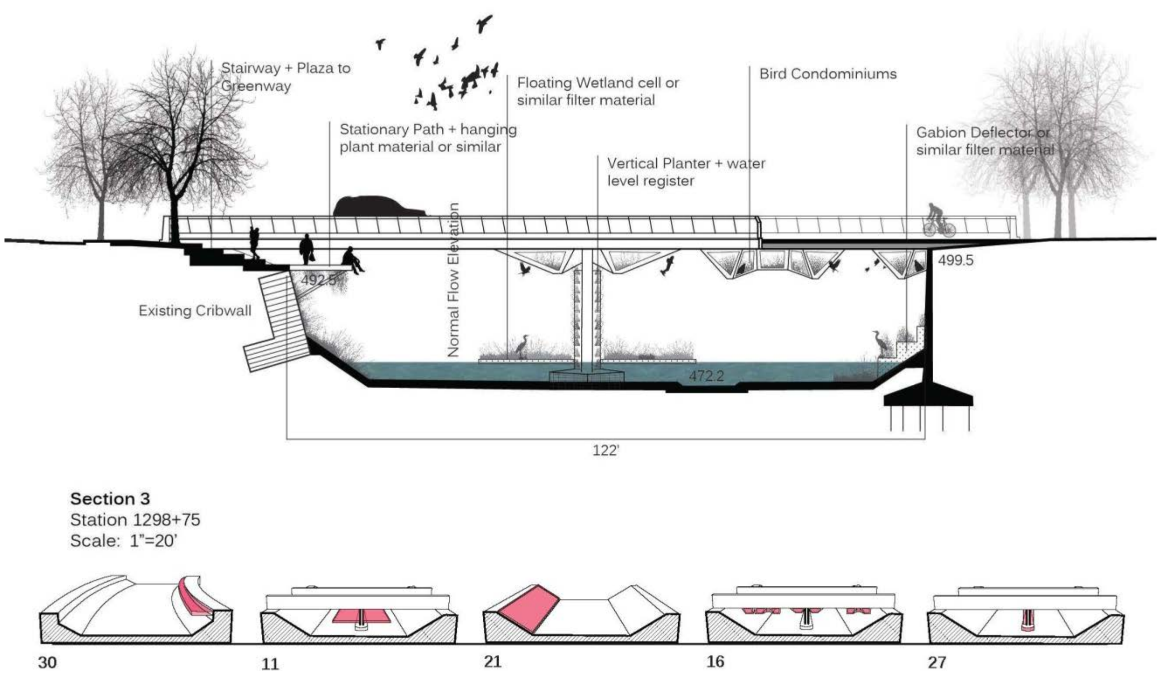


Figure 28. Section

Similarly, perspective drawings were used to collapse hybrid interventions into one drawing as a way to visualize, more clearly, what these areas would look like and how they would perform. These renderings allowed for further resolution of the hybrid interventions—what do these look like, how are they layered, what are they made of, and how users might engage these interventions. Here, my goal was to evoke a specific sense of place through certain design decisions. These drawings solicited many new challenges as materiality, function, longevity, aesthetics, and maintenance were all questioned (see Figures 29 through 34).

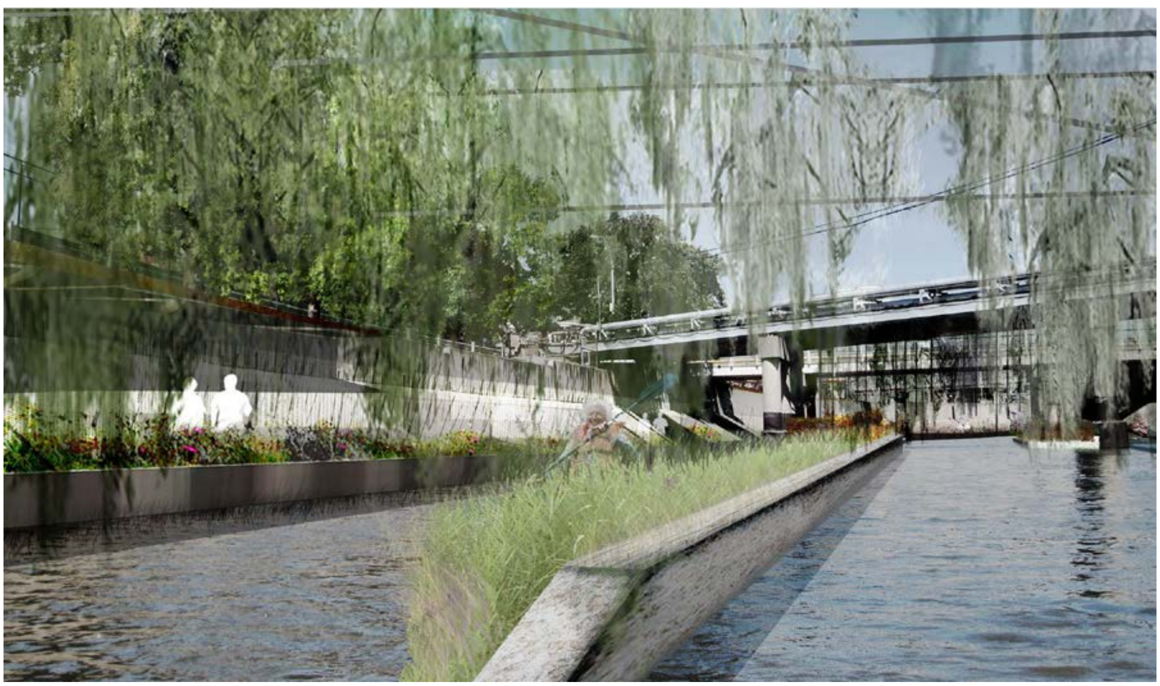


Figure 29. Rendering

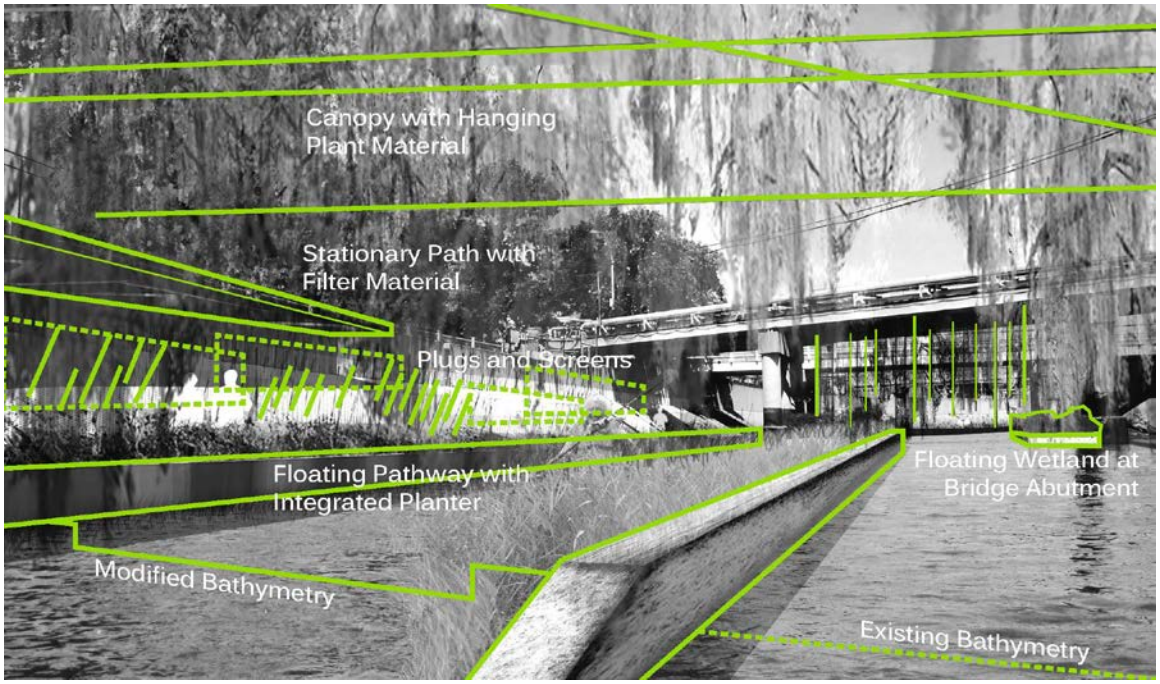


Figure 30. Diagram of Rendering

Figure 31. Rendering

Figure 32. Diagram of Rendering

Figure 33. Rendering

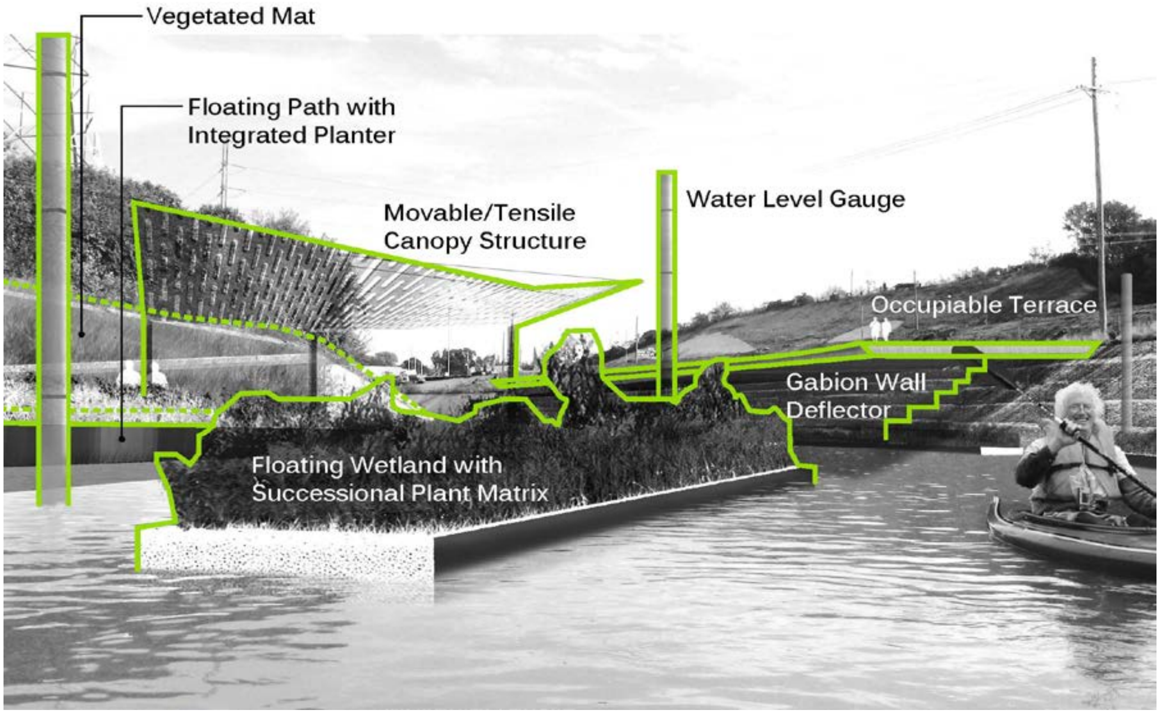


Figure 34. Diagram of Rendering

Long-Term Intervention Plan

While the hybrid types are investigated at a site level the entire Lower Mill Creek must be considered holistically with new strategies and hybrid interventions. A long-term Intervention Plan was developed that relies both on the intervention catalog and their deployment but also new strategies to create a productive and performative corridor. Strategies ranging from utilization of opportunity parcels that line the creek for either recreation space to remediation of waters through expanded riparian zone and diversion wetlands were conceptualized for the Lower Mill Creek. This Intervention Plan is seen as part of a growing landscape matrix along the Lower Mill Creek.

One of the strategies utilizes existing riparian corridors and their associated plant and animal life for birding purposes. This recreational activity populates the developed open space areas as active program while allowing for plant and animal life to thrive. This type of activity will help promote the Mill Creek and build upon its assets, existing and proposed.A long-term vision must be established in order for the Lower Mill Creek to achieve these objectives (see Figure 35).

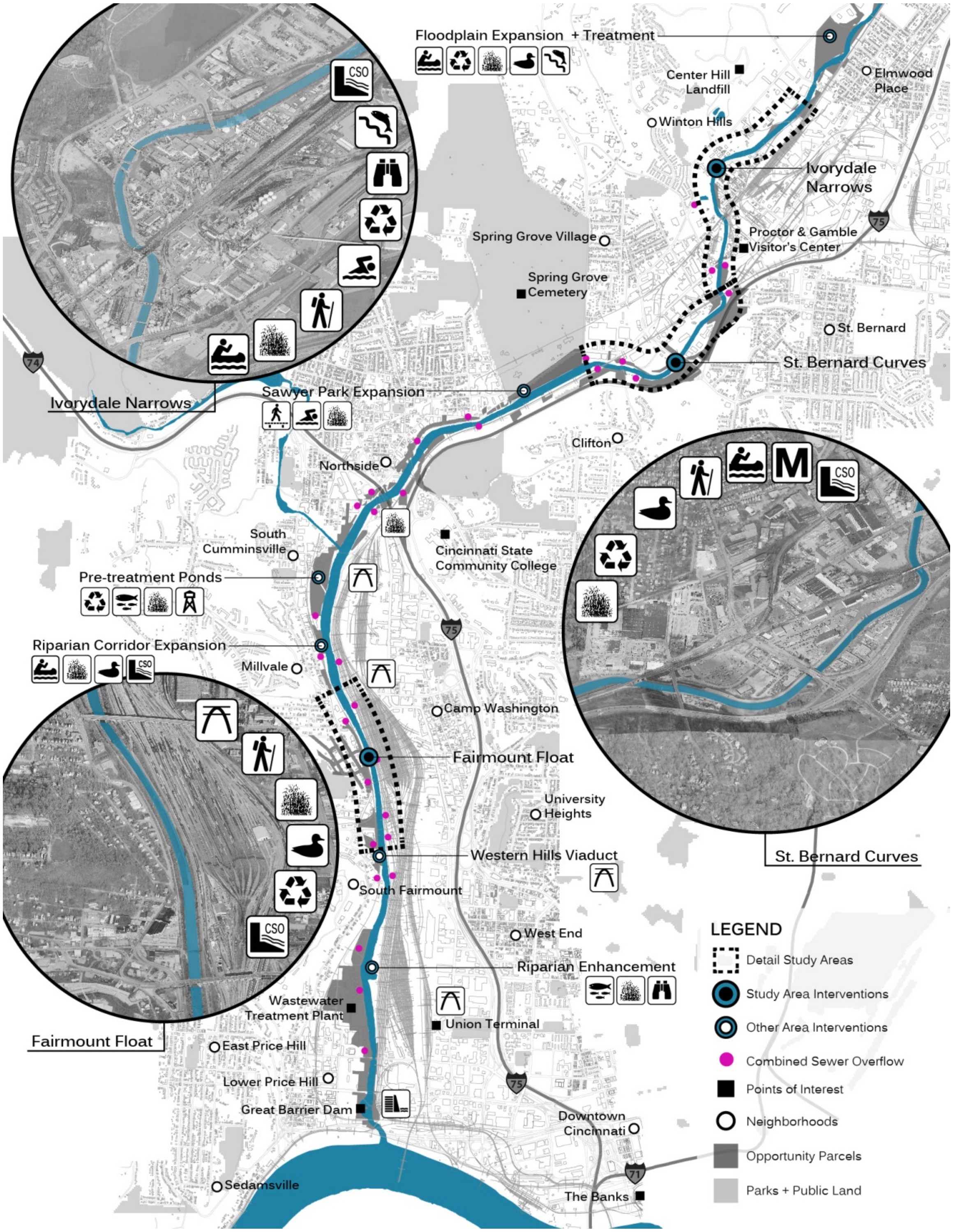


Figure 35. Long-term Intervention Plan

Chapter 6: Conclusions and Future Research

Conclusions

This study attempts to fill a gap in the literature around where stream restoration occurs and the techniques traditionally used in stream restoration projects. We have come to understand that traditional projects take place where space, politics, and infrastructure allow, and perhaps more importantly promote a naturalized end-point through strategies and techniques that reinforce a faux naturalized aesthetic.   Funding and research are targeting urban stream conditions. However, these funds are greatly misused. Although many of the projects target ecological factors and guiding objectives these projects can be lumped in to four main categories: bank stabilization, stormwater management, erosion control and re-vegetation.   Funding is not being applied is in the most degraded stretches of urban stream systems—concretized channels. These riverine systems are only as strong as their weakest link. Similarly, the Mill Creek is being studied and projects are developed for its restoration. However, these projects are focused in the Upper Mill Creek Watershed—areas were space, politics, and infrastructure allow. With terrestrial and in-stream efforts upstream the Mill Creek has begun to support new plant and animal life, house new program for residents, and educate the public about its importance locally and regionally. With efforts upstream in the Mill Creek watershed and ongoing support, we can begin to focus on those areas in need of enhancement most.

This project developed hybrid techniques influenced by traditional stream restoration techniques. By understanding the way in which each technique was effective, what it was made of, and how it performed, I was able to take those intentions and modify them for conditions like those of the Mill Creek and other concretized streams. This logic and conditional approach provided a thirty distinct hybrid intervention types, that could be used in different situations—vertical wall to trapezoidal, concrete-lined to crib wall.

Where I believe this project was particularly successful was in the process of engaging a specific site throughout the development of the intervention catalog—the hybrids. By working back and forth from site condition to hybrid intervention and its application the catalog became more and more robust. Its development began to deal with and question bathymetric options as well as potentials for CSO containment and treatment. It also allowed for a higher degree of resolution in how these hybrids might adhere, float, and engage with edges and river dynamics.

This project has taken a critical look at a major flaw in deployment and lack of discourse in ecological stream restoration. It has provided a base from which additional design studies and research can take place. It is important for this and similar projects to be engaged and for allied professions to understand the need and work toward a common goal. Although there is much effort and focus on ecological stream restoration in other areas of urban stream systems we must consider the system holistically and with a variety of strategies and approaches.

Future Research

This project identified a key gap in stream restoration literature—lack of discourse and vision for concretized streams. Throughout the project's process it has revealed an increasing number of gaps in both knowledge about, and arguments for, enhancing concretized streams for ecological performance.

Although this project has developed an intervention catalog hinged on and mimicking the effects and results of traditional stream restoration techniques this catalog is not yet exhaustive.

One exploration that was of high interest, but remained under-developed was in the bathymetric potentials of the channel. Continued efforts could begin to engage bathymetric modifications and in-stream structures that would mimic the complexity of natural stream bathymetry to promote conditional and channel surface heterogeneity. This investigation would allow for new potentials when improvements to the concrete channel are considered. The explorations of the bathymetric modifications could be informed by larger goals and objectives of aeration, differential pooling depths, increasing habitat zones and so forth.

Another area of interest in the development of the intervention catalog is the inclusion of a variety of additional conditions. While the study focused on three concrete-lined conditions—vertical wall, trapezoid, and a hybrid of the two—additional hybrids could be produced by designing with reference to specific adjacent land and infrastructural conditions. This is a relevant exploration due to the complexity of riverine systems and the array of stabilization and flood control techniques used—not only concrete.

Additional areas of research could begin to test hybrid techniques. This effort requires an understanding of the basic operations of the hybrid, its intentions, and its tectonics. Further development would explore materials, components, details, and construction budgets for each hybrid type. Furthermore, coordination with local authorities and funding agencies should be pursued to test and measure these hybrids. John Todd has done similar experiments with his Canal Restorer project in Fuzhou, China. There are current experiments with floating wetland cells in the Upper Mill Creek. Similar approaches, funding mechanisms, and hybrids would allow for a better understanding of how these interventions are designed, built, and deployed.

Another area in need of development is accessibility and associated development of trails and park systems adjacent to the Mill Creek. Although the study dealt with the Mill Creek channel almost exclusively, the highlighted access points could be further investigated as to their potential. A vision could be put forth that would allow communities to gain direct access through a variety of strategies—claiming vacant lots, access easements, existing right-of-ways, and so on. What does this mean for development in and around the Mill Creek over the next 25 years? Does industry move out and communities replace these areas? If so, what happens to the Mill Creek and our relationship to it? How do we break down the concrete and improve the channel to create a robust landscape and infrastructural system throughout the Mill Creek Valley? This strategy could be developed through community charrettes in order to identify key needs, access points, ideas of place-making, and most importantly to gain buy-in and support.

In closing, as designers we have the capacity to envision, project, prompt and provoke what we see through evocative imagination and new futures. The ability to respond to societal issues through intense research, beautiful narratives, and innovative solutions provides hope for our cities and the people who occupy them.

References

Allen, Stan. "Infrastructural Urbanism." *Points + Lines: Diagrams and Projects for the City*. New York: Princeton Architectural, 1999. N. pag. Print.

Amidon, J. (1995/2005). Land-Machine (Working paper).

Bernhardt, E. S. "ECOLOGY: Synthesizing U.S. River Restoration Efforts." *Science* 308.5722 (2005): 636-37. *Environment Complete*. Web. 19 Jan. 2013.

Bernhardt, Emily S., and Margaret A. Palmer. (2007). "Restoring Streams in an Urbanizing World." *Freshwater Biology*

Fletcher, David. "Flood Control Freakology: Los Angeles River Watershed." *The Infrastructural City: Networked Ecologies in Los Angeles*. Barcelona: Actar, 2008. N. pag. Print.

Georg, D. (2011, November 02). Interview by Author. [Personal Interview].

Giller, P. S. (2005). River restoration: seeking ecological standards. Editor's introduction. *Journal of Applied Ecology*.

GreenWorks, PC, ClearWater West, Fishman Environmental Services, Inter-Fluve, and KPF Consulting. *Willamette Riverbank Design Notebook*. Rep. N.p.: n.p., 2001. *Portland Online.com*. City of Portland, Bureau of Environmental Services, Portland Development Commission, May 2001. Web. 22 Jan. 2013. <www.portlandonline.com/ohwr/index.cfm?a=412529&c=51916>.

Hedeen, Stanley (1994). *The Mill Creek: An unnatural history of an urban stream*.

Hobbs, R. J., et. al. (2006). Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography*

Hobbs, R. J., & Cramer, V. A. (2008). *Restoration Ecology: Interventionist Approaches for Restoring and Maintaining Ecosystem Function in the Face of Rapid Environmental Change.*

Hung, Ying-Yu. "Landscape Infrastructure." *Landscape Infrastructure: Case Studies by SWA*. Basel: Birkhäuser, 2011. 14-19. Print.

Jansson, Roland, Christer Nilsson, and Bjorn Malmqvist. (2007). *Restoring freshwater ecosystems in riverine landscapes: the roles of connectivity and recovery processes*.

Juracek K.E. & Fitzpatrick F.A. (2003) Limitations and implications of stream classification. Journal of the American Water Resources Association, 39, 659–670.

Kondolf G.M. (1995) Geomorphological stream channel classification in aquatic habitat restoration – uses and limitations. Aquatic Conservation-Marine and Freshwater Ecosystems, 5, 127–141.

Leopold, Luna B., M. Gordon Wolman, and John P. Miller. *Fluvial Processes in Geomorphology*. San Francisco: W.H. Freeman, 1964. Print.

Lepori, F., D. Palm, and B. Malmqvist. "Effects of Stream Restoration on Ecosystem Functioning: Detritus Retentiveness and Decomposition." *Journal of Applied Ecology* 42.2 (2005): 228-38. *Environment Complete*. Web. 29 Oct. 2012.

Midwest Biological Institute. (2012). *2011 Biological and Water Quality Study of Mill Creek and Tributaries.* Rep. Cincinnati: Metropolitan Sewer District of Greater Cincinnati.

Lower Mill Creek Watershed Action Plan. Rep. N.p.: DRAFT, 2012. Print.

Niezgoda S.L. & Johnson P.A. (2005) *Improving the urban stream restoration effort: identifying critical form and processes relationships*. Environmental Management, 35, 579–592.

Nilsson C., Pizzuto J.E., Moglen G.E., Palmer M.A., Stanley E.H., Bockstael N.E. & Thompson L.C. (2003) *Ecological forecasting and the urbanization of stream ecosystems: challenges for economists, hydrologists, geomorphologists, and ecologists* – success and goals, considerations for scientific community

Otto, Betsy, Kathleen McCormick, and Michael Lasse. *Ecological Riverfront Design: Restoring Rivers, Connecting Communities*. Rep. no. 518-519. Chicago: American Planning Association, 2004. Print.

Palmer M.A., Bernhardt E.S., Allan J.D. et al. (2005) Standards for ecologically successful river restoration. *Journal of Applied Ecology* – establishing goals, shift in discipline focus, lessons learned

Shields F.D., Cooper C.M., Knight S.S. & Moore M.T. (2003) Stream corridor restoration research: a long and winding road. Ecological Engineering, 20, 441–454.

Solomon, Jonathan D. *13 Projects for the Sheridan Expressway: A.k.a. Jump, Slump, Hump, Bump--guide Specifications for a Post-Fordist Infrastructure*. New York: Princeton Architectural, 2004. Print.

Stantec. "Beargrass Creek Revisited – A Perspective on the Evolution of Stream Restoration over the Past 15 Years." Lecture. Mid-Atlantic Stream Restoration Conference. Rocky Gap, Maryland. 16 Nov. 2011. *Environment Complete*. Web. 26 Sept. 2012.

"Summary of the Clean Water Act." *EPA*. Environmental Protection Agency, n.d. Web. 12 Novr. 2012. <http://www.epa.gov/regulations/laws/cwa.html>.

Thompson, Douglas M. "Long-Term Effect of Instream Habitat-Improvement Structures on Channel Morphology Along the Blackledge and Salmon Rivers, Connecticut, USA." *Environmental Management* 29.2 (2002): 250-65. *Environment Complete*. Web. 29 Jan. 2013.

Todd, John. (2010). *Fuzhou, China Canal Restorer* – techniques, application, empirical

Todd, John, Erica Brown, and Erik Wells. (2003). Ecological design applied. *Ecological Engineering* – applications, case study, metrics and measurements of applications

United State of America. United State Department of Agriculture. Natural Resource Conservation Service. *Stream Corridor Restoration: Principles, Process, and Practices*. By Federal Interagency Stream Restoration Working Group. N.p.: n.p., 1998. Web. 22 Jan. 2013. <http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044574.pdf>.

"USACE-IWR Managment Measures Digital Library." *USACE-IWR Managment Measures Digital Library*. Institute of Water Resources, n.d. Web. 20 Jan. 2013. <http://www.pmcl.com/mmdl/MMMenu.asp>.

Woolsey, Sharon, Florence Capelli, Tom Gonser, Eduard Hoehn, Markus Hostmann, Berit Junker, Achim Paetzold, Christian Roulier, Steffen Schweizer, Scott D. Tiegs, Klement Tockner, Christine Weber, and Armin Peter. "A Strategy to Assess River Restoration Success." *Freshwater Biology* 52.4 (2007): 752-69. *Environment Complete*. Web. 31 Oct. 2012.

"What's the Problem?" *Project Groundwork*. Metropolitan Sewer District of Greater Cincinnati, n.d. Web. 17 Apr. 2013. <http://projectgroundwork.org/problems/index.htm>.

Appendix A: Traditional Techniques Spreadsheet

List of Stream Restoration Techniques
(include sources)

Goal: Improve ecological function in concretized streams to perform as well as traditional restoration projects
Objective: improve water quality
Objective: increased matrix connections (patches/corridors)
Objective: increased in-stream habitat quality & diversity

techniques that help achieve goals/objectives:

WQ	
turbidity	Source: Idaho DEQ
aeration	
temperature	
nutrients	

In-stream Habitat	
cover	Source: NEH 654 (USDA)
heterogenity structure	
spatial diversity	

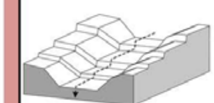
WQ	Habitat	Diagram	Image	Technique Name	Type	Effective Use	Results	How can this be Hybridized/ Adapted?	Sources
				rip-rap bank stabilization	natural	stabilizing banks; little/no tolerance for lateral movement; managed to keep plant material low/down; intro of vegetation	bank stabilization; no tolerance to lateral migration	by allowing some lateral percoloation/movement perforations would allow for water and plant material to take up spaces and allow concrete to maintain its crucial function	NRCS NEH-653 Appendix A
				drop/step	natural	aeration; energy dissipation; aids in grade control with channel slope increase; results in deeper pools at bottom of step	aeration; grade control; varying depth= temperatures differences=increased biodiversity (differing shelter/temp necessities)	longitudinal changes in the concrete could spur the development of drops/stepped portions of the Creek	North Carolina Cooperative Extension-Natural Stream Processes Fact Sheet 1;
				natural stream meander	natural	increases morphology potential; differing hydrological conditions	increased biodiversity & habitat; spatial heterogeneity; reconnections with floodplain (lateral); mosaics; hyporeic zone recharge;	allowing sediment build-up; form meandering channel within concrete (but still hard system??); new purchases of adjacent land; strategies for lateral connectivity coupled with new development protocols for inclusion of ecologically focused development restrictions	NRCS NEH-653 Appendix A; USACE-IWR MMDL; Niezgoda and Johnson_2005-improving stream restoration efforts;

Figure 36: Spreadsheet of Techniques

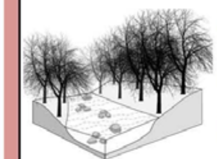
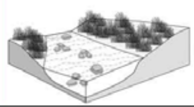
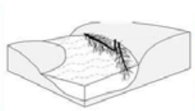
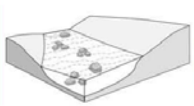
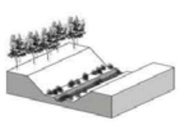
WQ	Habitat	Diagram	Image	Technique Name	Type	Effective Use	Results	How can this be Hybridized/ Adapted?	Sources
				Riparian Vegetation (cover-trees)	natural	increasing debris in stream; cooling/warming zones of stream (leaf litter, branch) to increase biodiversity and shelter	temperature regulation; leaf litter or CPOM potential; improving benthic layers; erosion control	addition of woody plant material; top of walls/banks; in banks; terraced banks that hang over walls; attached arbor structures; appendages to abutments; floating tree packs; structural overhangs that vary with stream height or depth; wooden pontoons or brush mattresses or sorts	Lepori, Palm, Malmqvist_2005 - Effects of stream restoration: detritus retention & decomp;
				Riparian Vegetation (remediation)	natural	has ability to remediate soils and water; decrease pollutants	improved water quality; increased habitat and erosion control	similar to above strategies; floating planters and wetlands; hydric species for remediative aspects; hanging structure?	Ecological Riverfront Design (APA); NRCS NEH-653 Appendix A
				tree cover (in-stream); LWD	natural	overhead cover; current deflection; scouring; deposition; trap sediment;	similar to log/brush structures felled trees increase heterogeneity in morphology and habitat; can stabilize/divert flows	wall mounted features; hanging planters and litter; how to introduce LWD-like materials...	NRCS NEH-653 Appendix A; USACE-IWR MMDL; Ashokan Watershed Stream Management Program; Sickle & Gregory 1990;
				in-stream boulders	natural	CPOM retention; increase structural heterogeneity; increase moss habitat (key in retentive factor of OM); scour holes and reduced velocity	shredding organic matter; increases benthic health	concrete structures, grooves, terracing, etc.	Ecological Riverfront Design (APA); NRCS NEH-653 Appendix A; Lepori, Palm, Malmqvist_2005 - Effects of stream restoration: detritus retention & decomp;
				streambank log, rootwad, boulder revetments	natural	absorbing boundary stress (lateral); enhance diversity plant and animal;	similar to tree cover in that it creates habitat and diversity thereof; slows and cools water;	boundary stress currently being dealt with; scrubbers on shear walls/enmbankments; structures for habitat suspended in water;	NRCS NEH-653 Appendix A
				two-stage channel	natural/ structural	conveying sediment; allowing floodplain; deeper areas for aquatic species; upper= more veg; coarser material in bed= increased habitat	increase biologic diversity; convey and flood regimes; sinuous lower channel can be self-designed	benching of trapezoidal lining; increased grooves for conveyance-what does low water-level look like?; is the main channel heavily vegetated? (LA river ideas);	Haung+Mitsch 2009 (stream restoration on a college campus)

Figure 37: Spreadsheet of Techniques

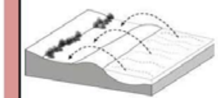
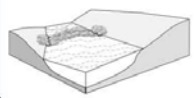
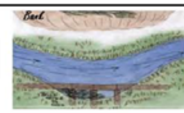
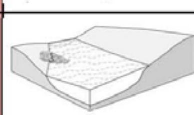
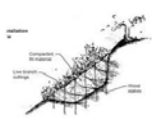
WQ	Habitat	Diagram	Image	Technique Name	Type	Effective Use	Results	How can this be Hybridized/ Adapted?	Sources
				wetland expansion	natural	floodplain growth; site remediation (if brownfield); have 3 useful zones	increase stream buffer; riparian growth; increase morphological potential of stream	development protocol's for increasing floodplain; property re-evaluation; derelict and residual properties for tributary expansion or wetland development	Ecological Riverfront Design (APA) p.58;
				weirs or sills	natural	structural and hydraulic diversity in uniform channels; pool habitat; collect/retain gravel	pooling and curling; aeration	terracing or pressure relieved gates that initially hold water then overflow (open with certain amoung of velocity, water depth)	NRCS NEH-653 Appendix A
				log/brush/rock shelters	natural/ structural	low gradient stream bend and meanders; where overhead cover is needed and pools exist; fish habitat	increased cover and habitat potential; key specie driven	scaffolding type of structure with material; decking or type of walkway integrated with habitat enhancing features;	NRCS NEH-653 Appendix A; USACE-IWR MMDL; USDA's Forest Service
				lunker structures	structural	cover for shelter, habitat; erosion prevention	increased cover and pool habitat; resting, nesting, etc of key species	similar to above log/brush/rock shelters; near abuttments; floating structures or suspended; integrate with walkway	NRCS NEH-653 Appendix A; USACE-IWR MMDL Interagency Stream Corridor Restoration Handbook
				wing deflectors (j-hook)	natural	protrusion from bank; constrict channel and accelerate flow; deflect flow away from bank; erosion control	minimize bank erosion; increase habitat and flow diversity;	reforming with concrete these types of structures; terracing and other protrusions;	NRCS NEH-653 Appendix A
				bank shaping and planting	natural	stabilizing banks where migration and erosion present; increase veg; prepare for other techniques	deterant of further incision; coupling of veg/remediation (see other strategies/structural approaches that could work in concert i.e., branch packing)		NRCS NEH-653 Appendix A; USACE-IWR MMDL Interagency Stream Corridor Restoration Handbook
				Branch packing	natural	branches fill holes with soil atop-slumps, etc; produces filter barrier; rapid vegetation	bank stability; erosion control; trapping debris on slopes; increased infiltration; drying wet sites;	embedding materials in cribwalls; concrete reshaping in similar form and planted or utilized as programmatic space; ID slumps and introduce some	NRCS NEH-653 Appendix A; USACE-IWR MMDL Interagency Stream Corridor Restoration Handbook

Figure 38: Spreadsheet of Techniques

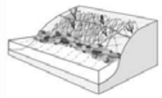
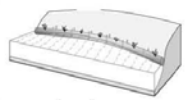
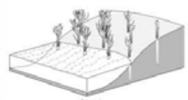
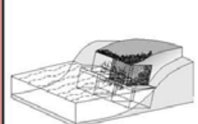
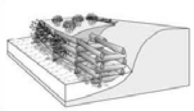
WQ	Habitat	Diagram	Image	Technique Name	Type	Effective Use	Results	How can this be Hybridized/ Adapted?	Sources
				brush mattress	natural	immediate protective cover of bank; sprouting vegetation; sediment capture;	vegetation and streamside habitat; bank protection	layering of vegetal material against encasement; plugs in concrete to enduce sprouting vegetation; sediment capture??	NRCS NEH-653 Appendix A; USACE-IWR MMDL Interagency Stream Corridor Restoration Handbook
				coconut fiber roll	natural	protect from erosion; trap sediment to increase plant growth within roll	moderate stabilization; minor disturbance; quick establishment of plant material	can this be employed as is?; what can cocount fiber do in encased areas?; the concrete reduces ability for this to occur…veg mat of sorts?	NRCS NEH-653 Appendix A; USACE-IWR MMDL Interagency Stream Corridor Restoration Handbook
				dormant post plantings	natural	increase channel roughness, reduce flow velocities; sediment deposition and revegetation	increased vegetation cover and channel roughness; sediment trap/deposition;	plugs in embankments; artistic expression of order and maturation; plants may be ordered in similar levels of innudation/exposure to water levels throughout year;	NRCS NEH-653 Appendix A; USACE-IWR MMDL Interagency Stream Corridor Restoration Handbook
				vegetated gabions	natural/ structural	protect steep slopes; giving moderate support;	slope integrity, especially where slopes must be steeper than appropriate for riprap; channel toe establishment and retention;	gabions in current situation; voids provide habitat allowances but restrict flow if protudes into channel; conceptual properties used in channel; floating mechanisms with high porousity which can house soil that is accumulated; aesthetic potential is high	NRCS NEH-653 Appendix A; EPA's Office of Wetlands, Oceans and Watersheds, the USACE Waterways Experiment Station, and extracted from Maccaferri Gabions, Inc.,
				joint plantings	natural	re-establish vegetation; retaining banks and soil fines for roots; improve drainage	riparian habitat; roots provide mat for root establishment and water drainage	little worry for lateral migration; plugs in encasement; no drainage allowed/connection to water table;	NRCS NEH-653 Appendix A; USACE-IWR MMDL Interagency Stream Corridor Restoration Handbook
				live cribwalls	natural/ structural	protection of near vertical banks; immediate protection and est. woody species; areas of high velocity	stabilize near vertical conditions; accelerate plant and woody species growth; natural streambank appearance	appendage to embankments; planting possibilities of wall; bucket planters or vertical arbor structure/grid;	NRCS NEH-653 Appendix A; USACE-IWR MMDL Interagency Stream Corridor Restoration Handbook

Figure 39: Spreadsheet of Techniques

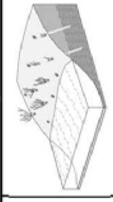
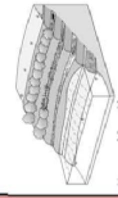
WQ	Habitat	Diagram	Image	Technique Name	Type	Effective Use	Results	How can this be Hybridized/ Adapted?	Sources
				live stakes	natural	living root mat great for water percolation and binding soil;	streamside habitat; living root mat for stabilization of bank and erosion control if done in high quantities	hanging grid structures; veggie mat or suspended plant material; integrated walk with cover and structure;	NRCS NEH-653 Appendix A; USACE-IWR MMDL; EPA's Office of Wetlands, Oceans and Watersheds, and Alaska Department of Fish and Game
				vegetated geogrids	natural	rebuild and vegetate banks; quick veg establishment; creating new, well reinforced bank	rebuilt bank; configuring new banks; riparian vegetation (habitat, cover, leaf litter, etc.)	infill of bank condition with these strategies; can lining come out then?; does section shift inward?; terracing with plant materials; wall plugs and hanging material	NRCS NEH-653 Appendix A; USACE-IWR MMDL Interagency Stream Corridor Restoration Handbook; Gray/Sotir; U.S. Dept. of Agriculture

Figure 40: Spreadsheet of Techniques

Appendix B: List of Resources for Techniques

Huang, Jung Chen, William J. Mitsch, and Li Zhang. "Ecological Restoration Design of a Stream on a College Campus in Central Ohio." *Ecological Engineering* 35.2 (2009): 329-40. *Environment Complete*. Web. 25 Sept. 2012.

Lepori, F., D. Palm, and B. Malmqvist. "Effects of Stream Restoration on Ecosystem Functioning: Detritus Retentiveness and Decomposition." *Journal of Applied Ecology* 42.2 (2005): 228-38. *Environment Complete*. Web. 29 Oct. 2012.

Niezgoda S.L. & Johnson P.A. (2005) *Improving the urban stream restoration effort: identifying critical form and processes relationships*. Environmental Management, 35, 579–592.

North Carolina Stream Restoration Institute. N.p.: North Carolina Stream Restoration Institute, n.d. *Rivercourse Factsheets*. NORTH CAROLINA COOPERATIVE EXTENSION SERVICE, June 1999. Web. 27 Jan. 2013. <http://www.bae.ncsu.edu/programs/extension/wqg/sri/rv-crs-1.pdf>.

Otto, Betsy, Kathleen McCormick, and Michael Lasse. *Ecological Riverfront Design: Restoring Rivers, Connecting Communities*. Rep. no. 518-519. Chicago: American Planning Association, 2004. Print.

United State of America. United State Department of Agriculture. Natural Resource Conservation Service. *Stream Corridor Restoration: Principles, Process, and Practices*. By Federal Interagency Stream Restoration Working Group. N.p.: n.p., 1998. Web. 22 Jan. 2013. <http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044574.pdf>.

"USACE-IWR Managment Measures Digital Library." *USACE-IWR Managment Measures Digital Library*. Institute of Water Resources, n.d. Web. 20 Jan. 2013. <http://www.pmcl.com/mmdl/MMMenu.asp>.

Appendix C: Hybrid Technique Diagrams

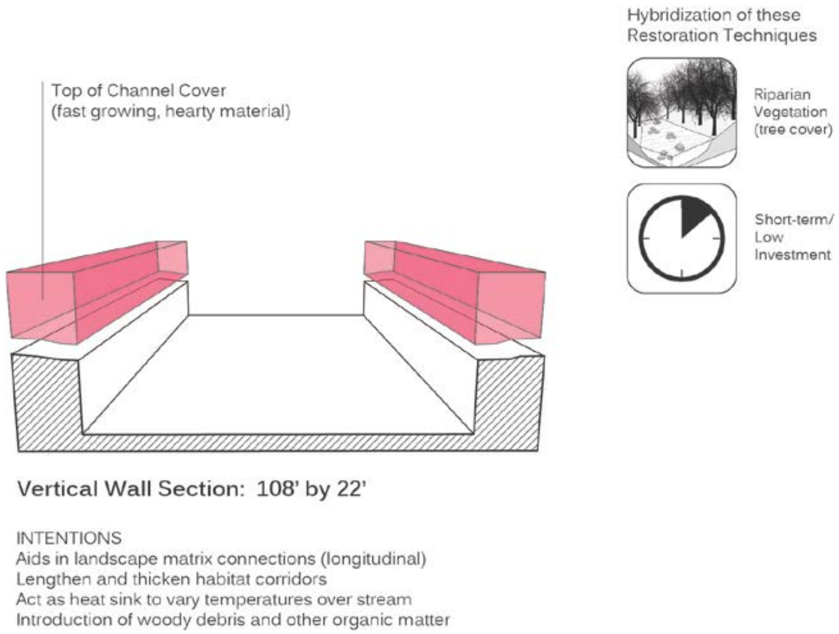


Figure 41. Shearwall Channel Hybrid Technique

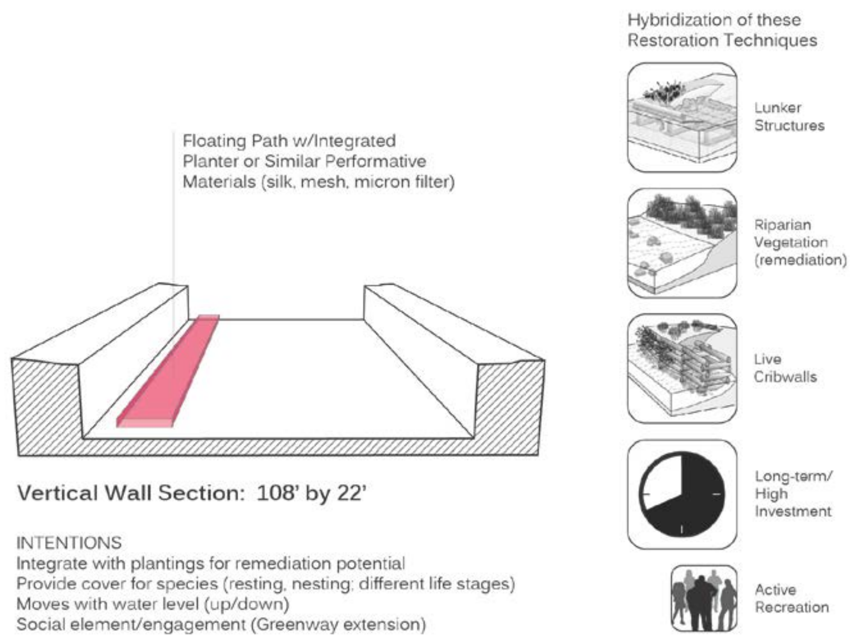


Figure 42. Shearwall Channel Hybrid Technique

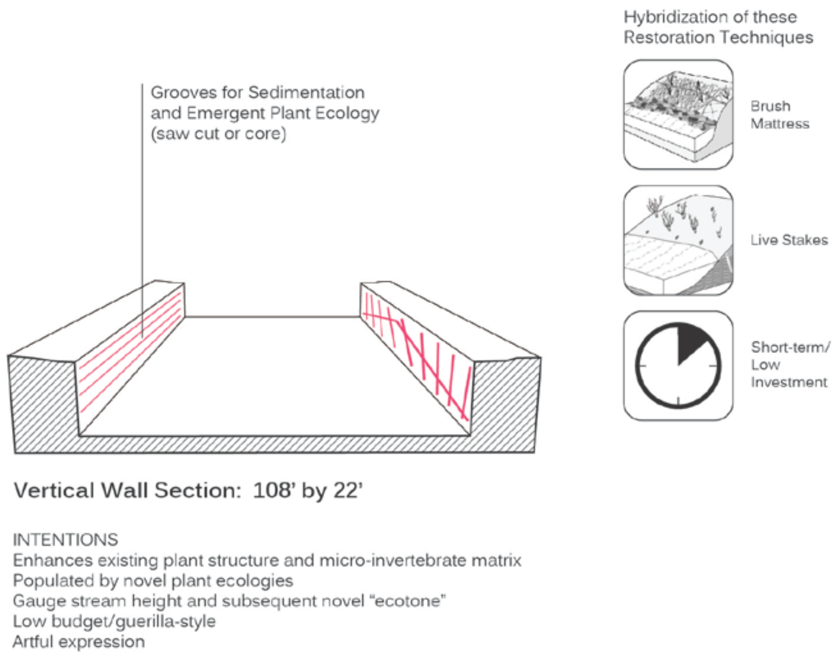


Figure 43. Shearwall Channel Hybrid Technique

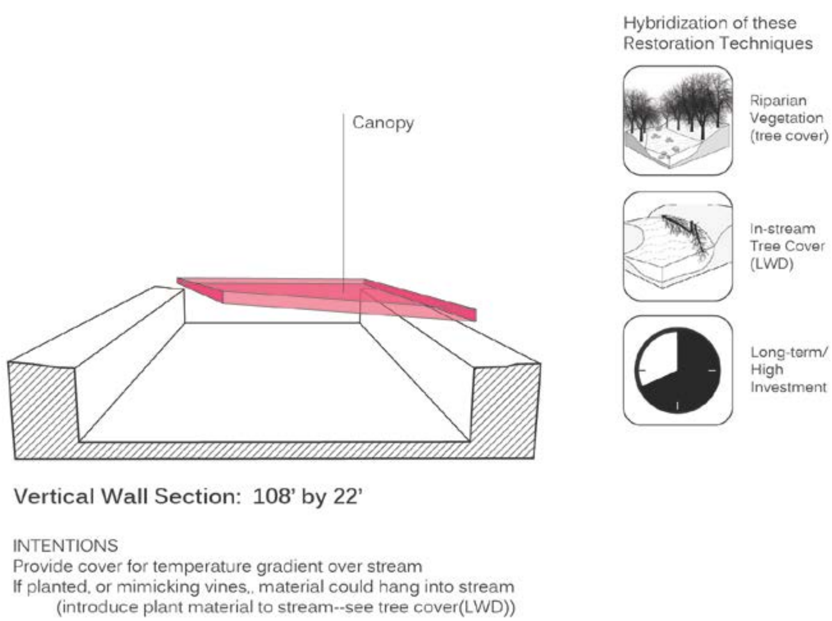


Figure 44. Shearwall Channel Hybrid Technique

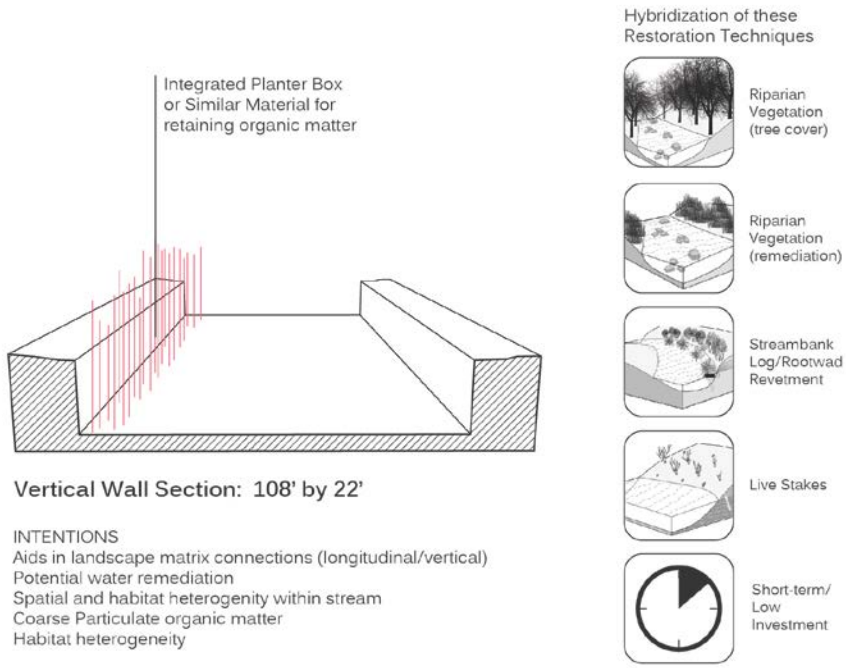


Figure 45. Shearwall Channel Hybrid Technique

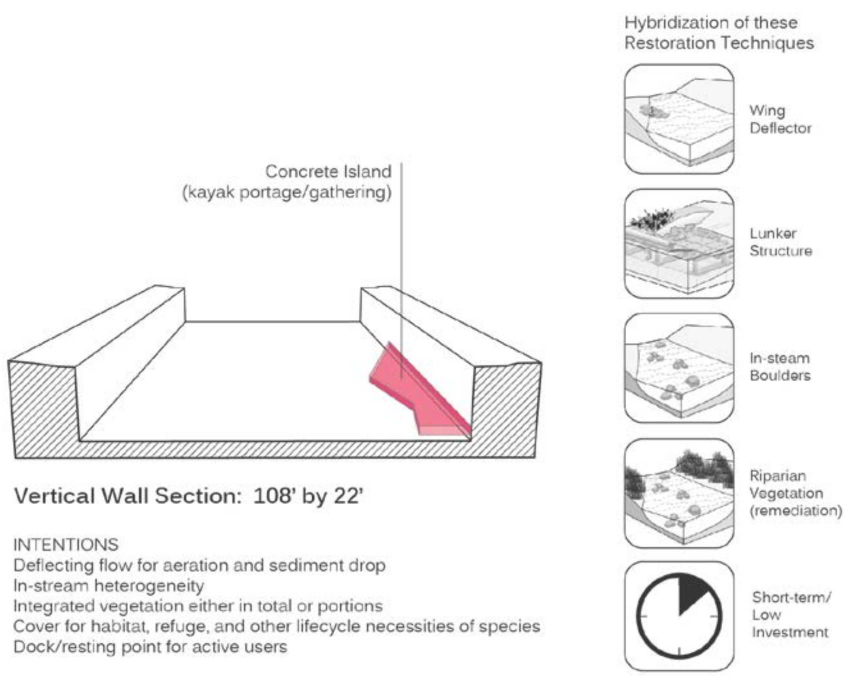


Figure 46. Shearwall Channel Hybrid Technique

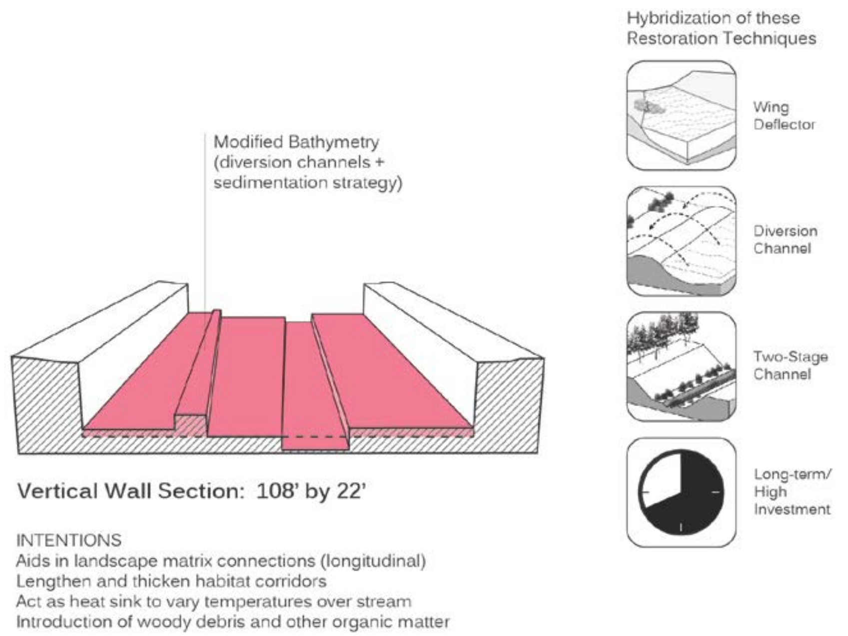


Figure 47. Shearwall Channel Hybrid Technique

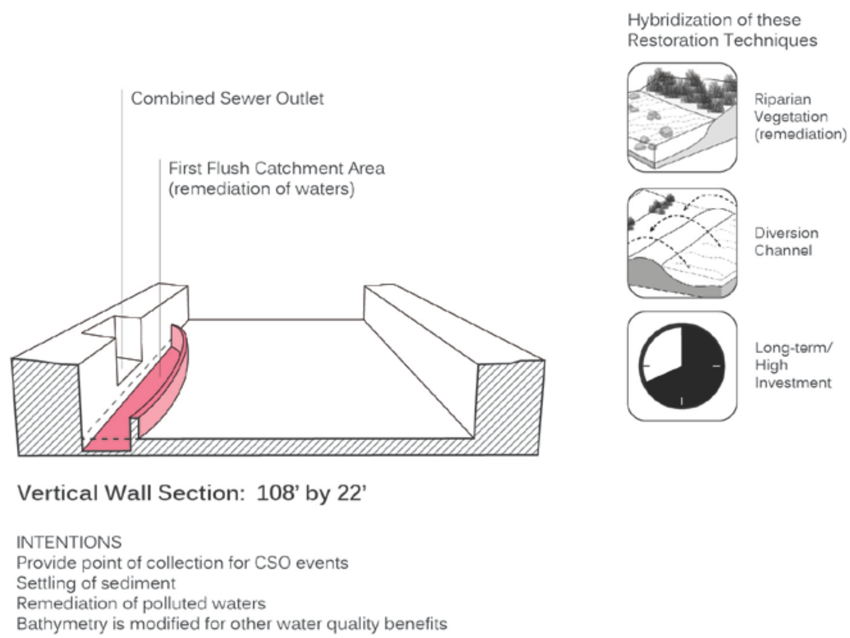


Figure 48. Shearwall Channel Hybrid Technique

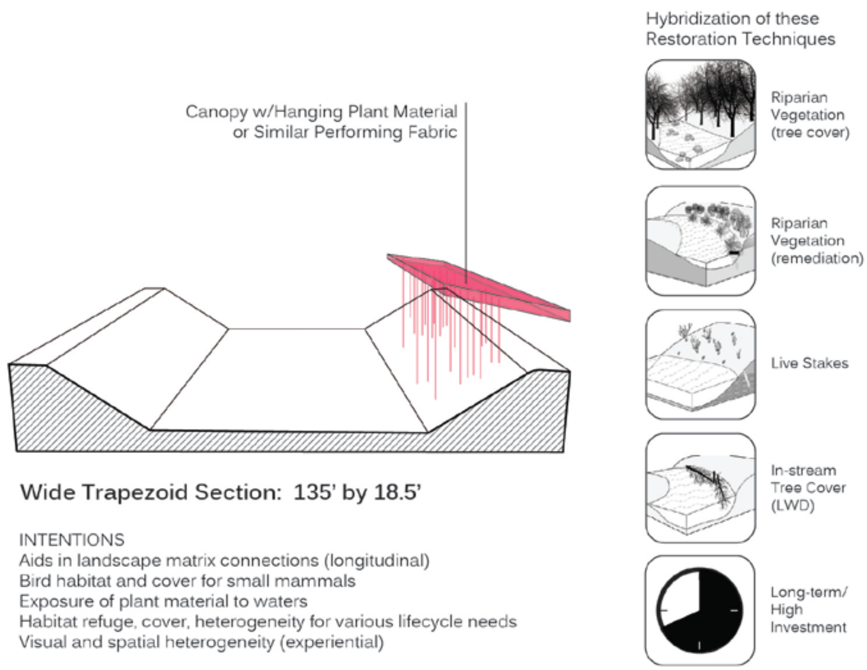


Figure 49. Trapezoidal Channel Hybrid Technique

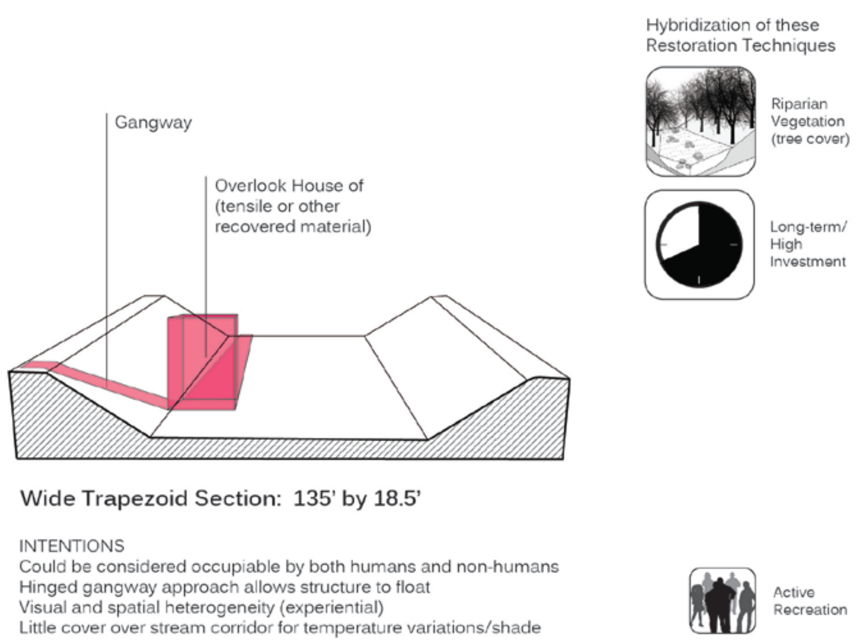


Figure 50. Trapezoidal Channel Hybrid Technique

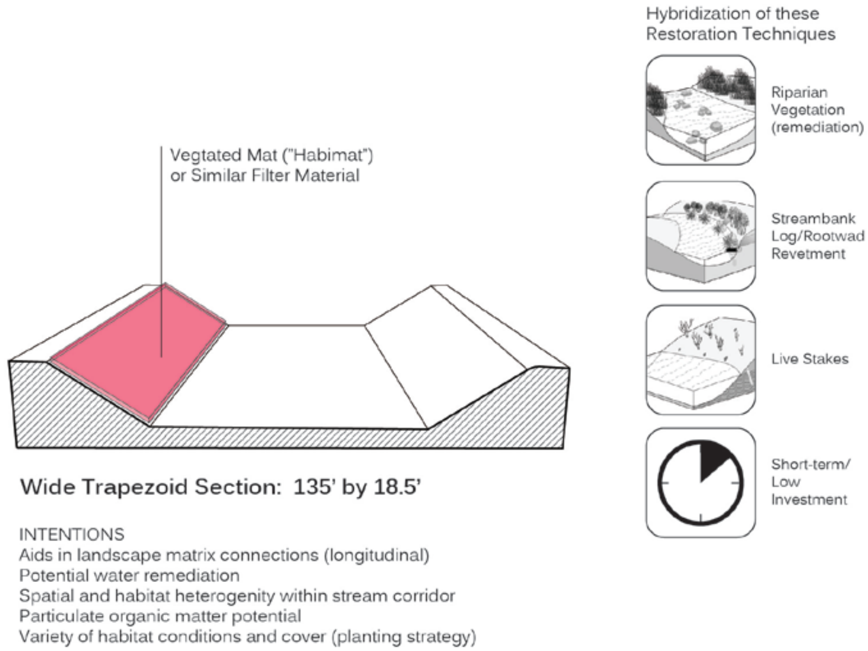


Figure 51. Trapezoidal Channel Hybrid Technique

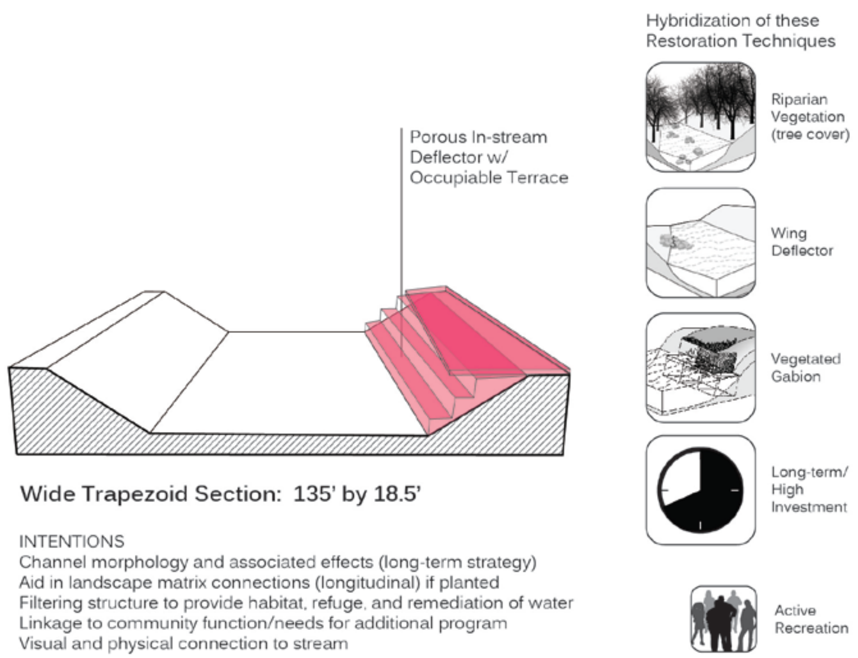


Figure 52. Trapezoidal Channel Hybrid Technique

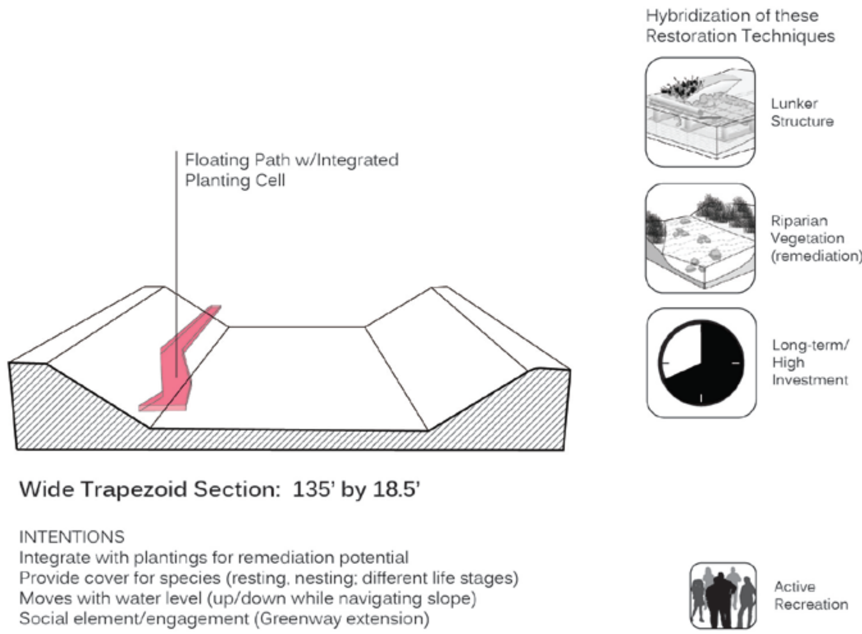


Figure 53. Trapezoidal Channel Hybrid Technique

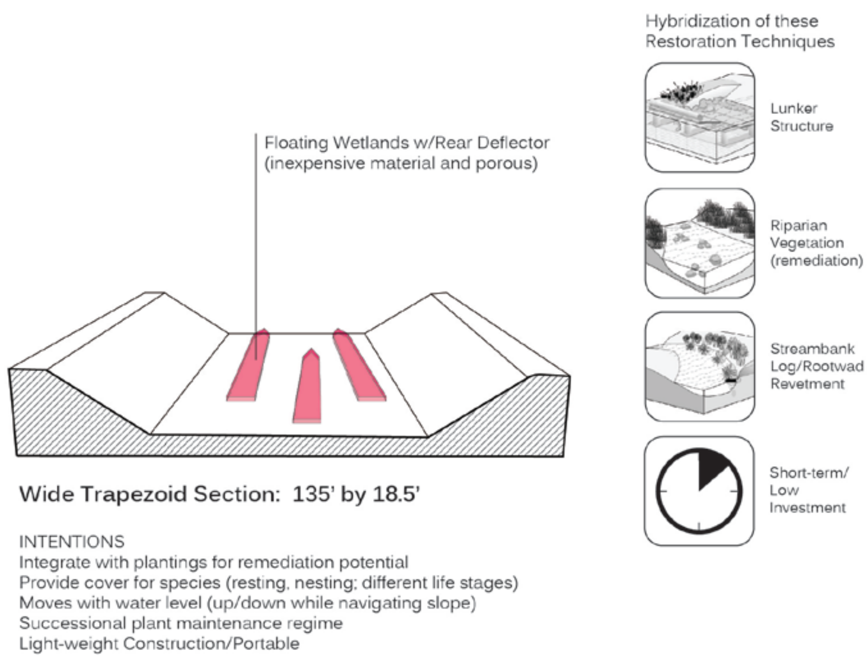


Figure 54. Trapezoidal Channel Hybrid Technique

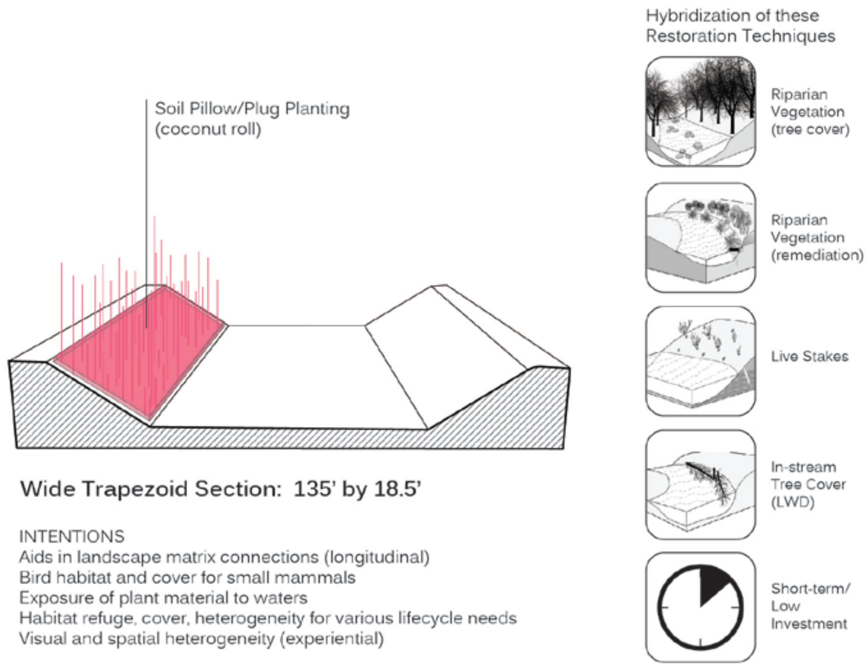


Figure 55. Trapezoidal Channel Hybrid Technique

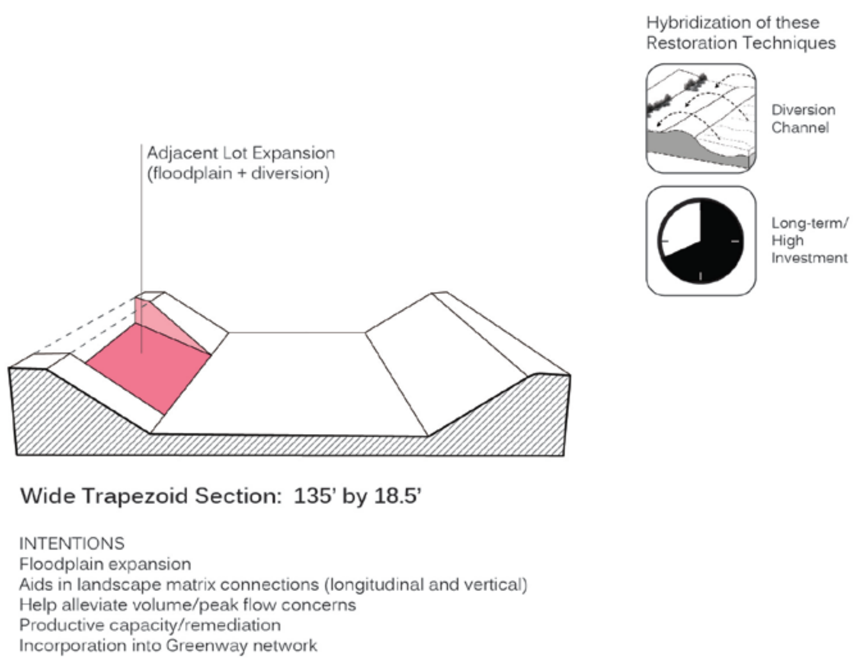


Figure 56. Trapezoidal Channel Hybrid Technique

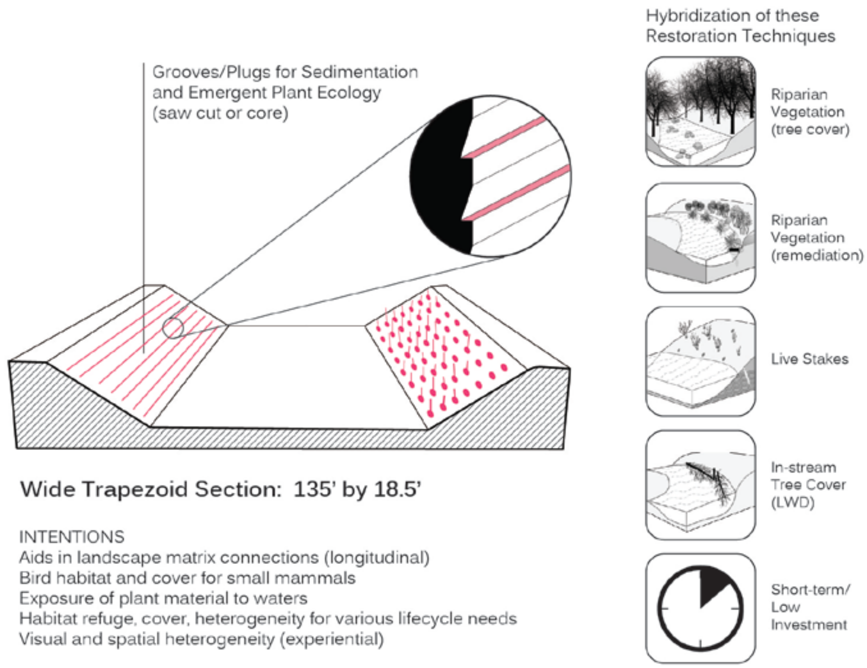


Figure 57. Trapezoidal Channel Hybrid Technique

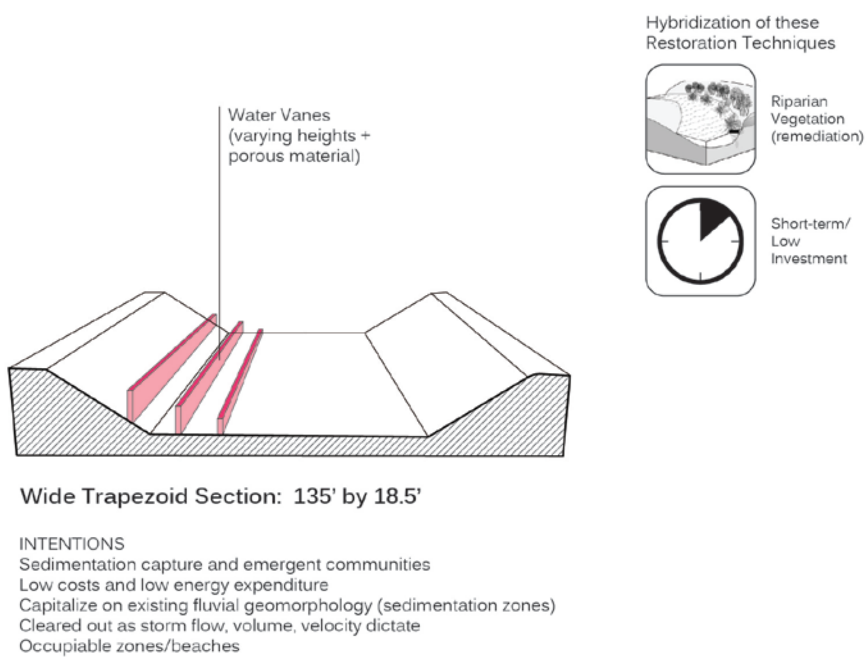


Figure 58. Trapezoidal Channel Hybrid Technique

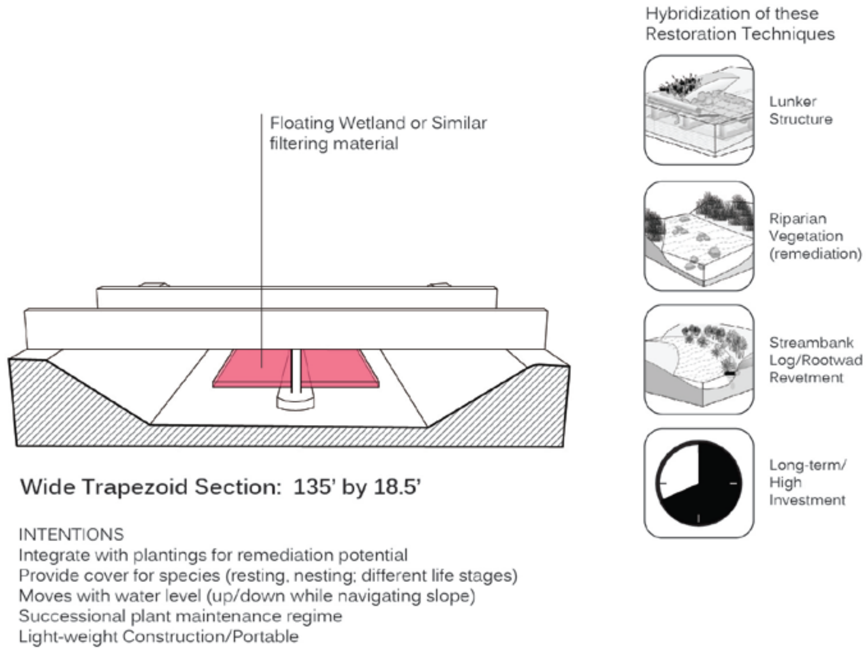


Figure 59. Trapezoidal Channel Hybrid Technique

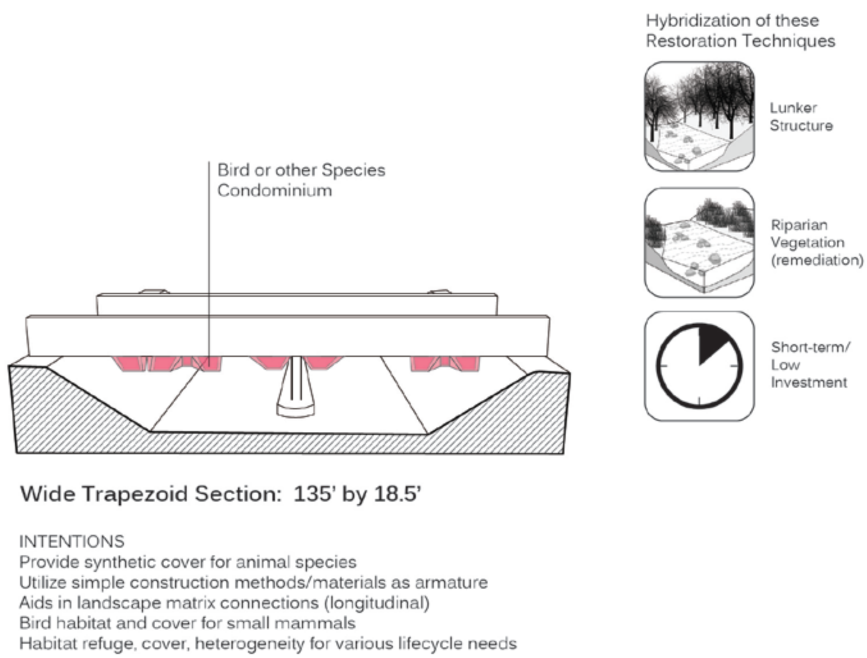


Figure 60. Trapezoidal Channel Hybrid Technique

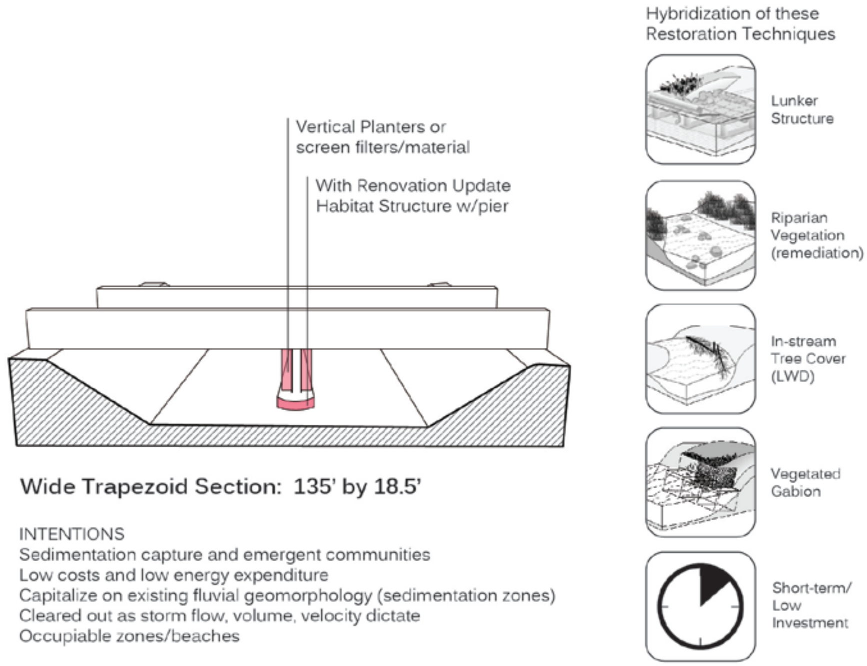


Figure 61. Trapezoidal Channel Hybrid Technique

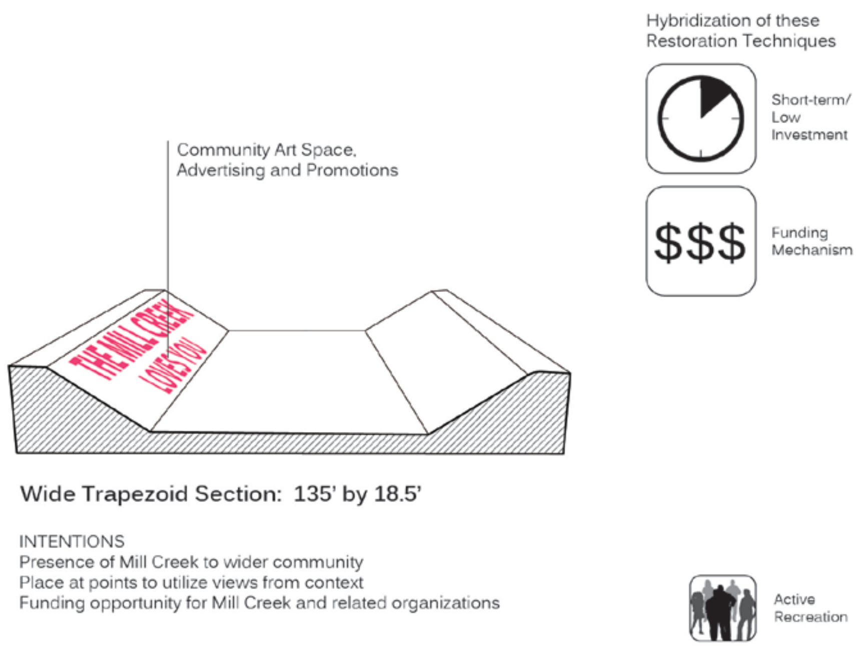


Figure 62. Trapezoidal Channel Hybrid Technique

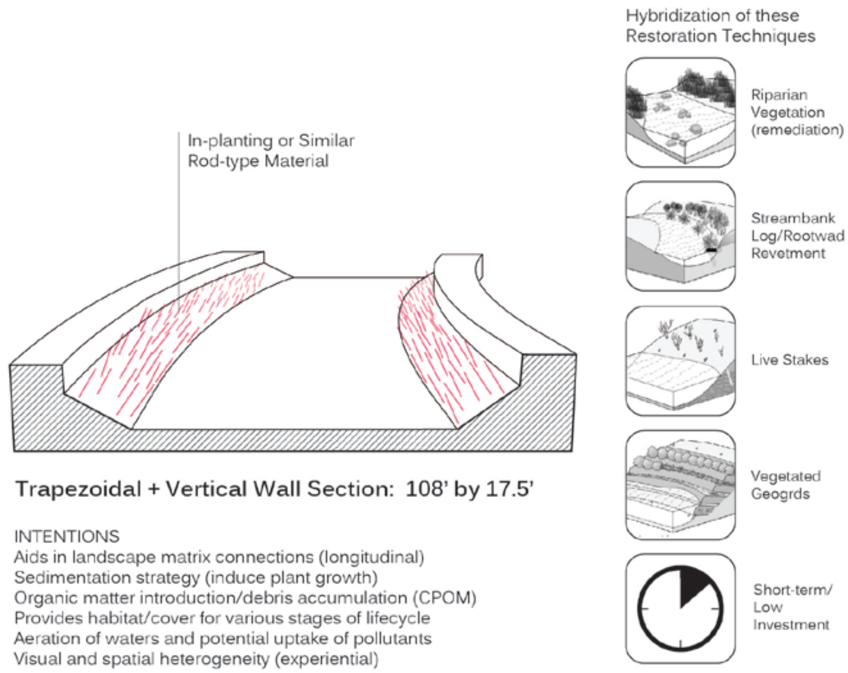


Figure 63. Hybrid Channel Hybrid Technique

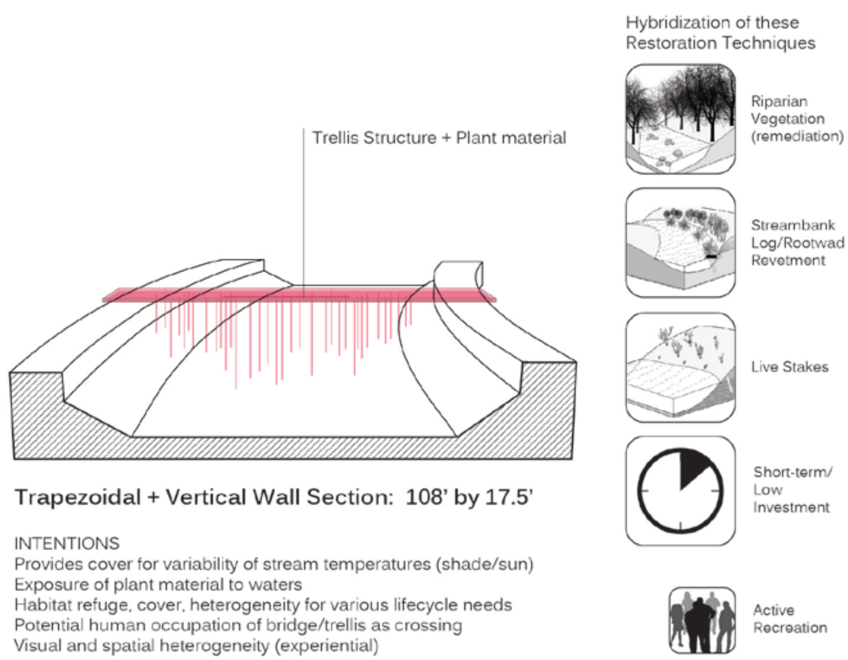


Figure 64. Hybrid Channel Hybrid Technique

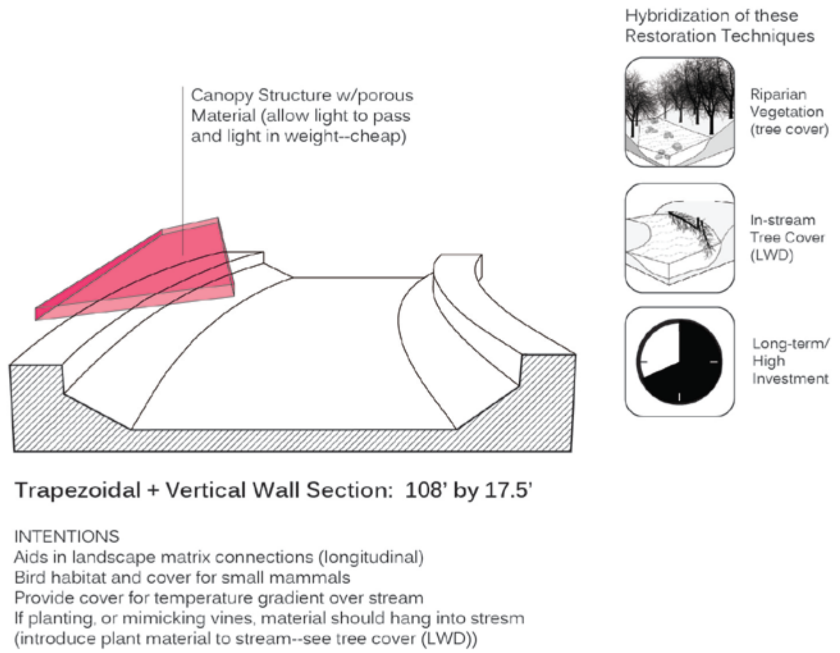


Figure 65. Hybrid Channel Hybrid Technique

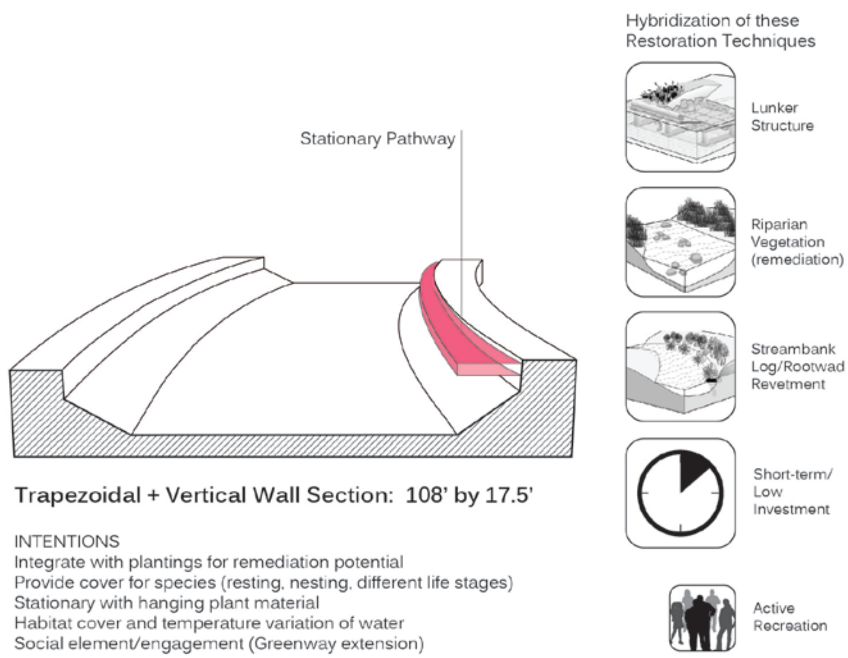


Figure 66. Hybrid Channel Hybrid Technique