Table 4-3: Estimated Costs to Implement Potential Habitat Improvements

Reach	Construction of Off-Channel Bays	Removal of Vertical Wall Banks	Riprap Replacement	Construction of bank Pocket Areas	Total
North Shore Channel	$19,698,987	$0	$6,737,280	$3,486,163	$29,922,430
North Branch Chicago River	$14,966,114	$67,056,000	$15,924,480	$572,666	$98,519,259
Chicago River	$0	$0	$0	$0	$0
South Branch Chicago River	$1,961,371	$67,056,000	$2,449,920	$562,876	$72,030,167
Bubbly Creek	$1,918,733	$8,382,000	$612,480	$110,128	$11,023,341
Chicago Sanitary and Ship Canal	$53,383,402	$301,752,000	$20,211,840	$3,830,007	$110,953,249
Cal-Sag Channel	$41,188,791	$100,584,000	$52,673,280	$1,970,068	$115,948,939
Little Calumet River	$5,201,897	$10,058,400	$6,737,280	$0	$21,997,577

Based on these reach-by-reach estimates, the total estimated cost for all of the potential habitat improvements, system-wide, is more than $460 million. It should be reiterated that this total does not include costs for land acquisition, demolition of existing structures, removal or relocation of utilities and infrastructure, or potential environmental cleanup costs. These items could increase costs substantially, For example, the removal of 33 miles of vertical wall banks included in the estimate above would require acquisition of approximately 80 acres of land along the CAWS.

4.5 LIMITATIONS OF THIS EVALUATION

It should be noted that the assessment of habitat improvement potential described above has a number of inherent limitations. The most significant of these are described below:

- The evaluation of habitat improvement potential is based on application of the CAWS habitat index developed in this study, which is based on analysis of the statistical relationship of habitat attributes with fish metrics.

- A number of apparent habitat attributes were described in Section 2 of this report, which are either so lacking in the CAWS that they do not register a statistical relationship with the fish data (such as off-channel refuge), or they have not been adequately measured (such as in-channel structure). The relative importance of these habitat attributes has not been quantitatively accounted for in this assessment and some of them may be improvable. On the other hand, more importantly, if they had been accounted for, the level of impairment would have been even greater.

- The assessment presented above treats habitat attributes independently. However, synergies may exist between attributes that make their improvement together greater than their individual sums. But there is no way to assess this possible effect at this time.

5. SUMMARY OF FINDINGS

As stated in the introduction, this part of the CAWS Habitat Evaluation and Improvement Study was undertaken to identify which primary habitat impairments can potentially be improved. The following objectives were identified:

- Given the habitat impairments identified in the Study, determine what physical habitat improvements, if any, can feasibly be implemented in the CAWS.
- Determine, to the extent possible with existing information, what the potential benefit of habitat improvement in the CAWS would be to fish.
- Estimate the potential cost of habitat improvement.

These objectives have been addressed in this report and the assessment presented in the report support the following findings:

- Only six of the primary habitat impairments identified in this Study have improvement potential.
- Reach-wide improvement of the primary habitat impairments that can be improved would result in habitat index score increases between 0 and 13 points (from zero to 38% increase).
- These potential improvements do not significantly alter the relative habitat index scoring of the CAWS reaches.
- The percent change in habitat index scores for the CAWS reaches is less than the variability in fish data, meaning that it may be difficult to measure significant improvements in fisheries as a result of the habitat improvements.
- The estimated cost of the habitat improvements described in this report is more than $460 million system-wide and this estimate is likely low as it does not include costs for land acquisition, demolition of existing structures, removal or relocation of utilities and infrastructure, or potential environmental cleanup costs associated with excavation next to the CAWS.

It should be noted that some potential habitat improvement measures discussed in this report may be infeasible, but for purposes of identifying improvement potential, they were carried through the discussion. As discussed in Section 4.1, a primary example of this is the removal of vertical-walled banks. It is technically possible that portions of vertical-walled banks might be removed and replaced with naturalized banks, but the cost of doing this over long reaches would likely be impractical and unaffordable. Therefore, discussion of this and similar measures in this report should not be construed as a recommendation or endorsement of those actions.

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APPENDIX A:

BIBLIOGRAPHY OF LITERATURE REVIEWED FOR INFORMATION OF HABITAT IMPROVEMENT IN ARTIFICIAL AND HIGHLY MODIFIED WATERWAYS

(BIOENGINEERING GROUP, 2009)

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APPENDIX B:

HABITAT IMPROVEMENT TECHNIQUE FACT SHEETS

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Linear Shallows

DEMONSTRATED USE SETTINGS:

- Canals/Rivers
- Lakes

MEASURE HIGHLIGHTS:

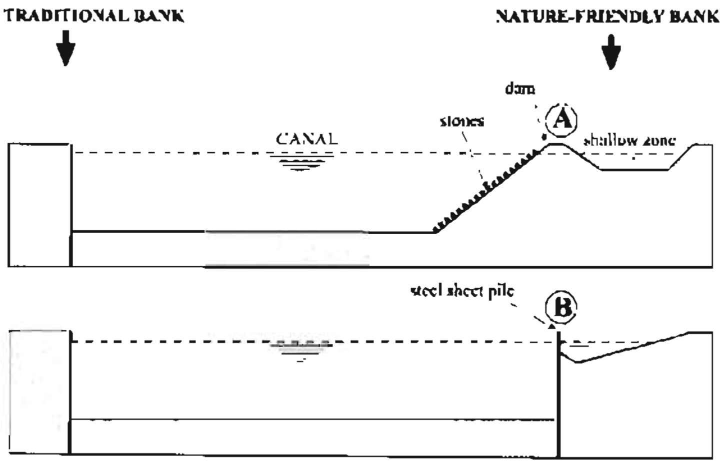
- Sheltered shallow zones connected to areas with high wave energy impacts and lacking variability in depth
- Can be built with or without vegetation
- Built from standard construction materials
- Located either outside or within existing channel
- Allows variations in water depth and/or saturated soils

BENEFITS PROVIDED:

- Shallow refugia for fish
- Spawning, Nesting Habitat for multiple species
- Herptile habitat
- Habitat for rooted aquatic and emergent macrophytes
- Physical habitat for low-energy plants and animals

Method Description – Linear shallows are used to introduce variation in form, vegetation, and habitat conditions into otherwise uniform, harsh, and barren channel settings. By creating protected yet connecting areas of shallow water underlain by hydric soils parallel to the active canal, this measure allows the introduction of riparian wetland habitat, nesting, and spawning grounds, and off-channel refugia for fish. Linear shallows have been constructed along artificial canals using two methods. One method requires driving sheetpiles within the cross section of an earth embankment canal. Another method employs the construction of a sheet pile wall or riprapped berm running parallel along the lateral landward edge of the canal. The waterward edge of the barrier may slope quite steeply to the canal, and the landward zone is then filled with suitable substrate to allow shallow water depth. Shallow zones may either been maintained at depth or allowed to silt-in enough to develop rooted aquatic and emergent macrophytes as well as helophytes. Besides providing protection from wave action for all life stages of fish, shallows provided much-needed shallow water habitat for fish spawning and rearing. Shallows must intermittently open to the main canal to enable connectivity of the habitats and for fish to escape from navigational traffic to the calmer waters. In order to allow water and habitat circulation without exposing the linear shallows to excess wave energy, baffle type openings are typically used. This measure has been utilized and studies waterways such as the Twentekanaal and Zuid-Willemsvaart canal in the Netherlands which are similar to many European canals due to general absence of aquatic vegetation, little to no functional riparian zone, and flow dynamics are severely impacted, along with reduced hydrologic connectivity to floodplains or spawning/nursery areas. Additionally this measure has been used and reported on at Lake Havel in Germany where navigational and recreational traffic create suspended sediment impacts, and high nutrient loading and poor water quality caused further stress to aquatic life.

Habitat Enhancement Values – Natural waterbodies depend on diverse slopes, substrates, and plant communities in riparian areas to provide an array of habitat niches, and combinations thereof, that support and foster various phases of the life cycles of many fish, birds, herptiles, and invertebrates. Canal construction removes variability in the microhabitats of water bodies and creates limiting factors for numerous organisms. Artificial canals feature simple cross sections, highly uniform profiles, and harsh wave energy levels leading to an absence and/or impoverishment of riparian habitats. Navigational traffic is high, with high wave energy in otherwise limnetic zones. Linear shallows provide an arrangement wherein a wide range of water depths, soil types, and plant communities may be established according to targeted habitat objectives. Typical linear shallows include a continuum of unvegetated deep to shallow habitats as well as emergent and submerged macrophytic vegetation. Substrate may be fine to coarse, but is protected from resuspension due to the sheltered location. Fish species adapted to low energy zones generally use shallow aquatic vegetated zones for spawning and nursery habitat. Wading birds use shallow open water habitats for feeding. Herptiles and small mammals use soft soil embankments for nesting and hibernation. The variation in water depths and vegetation provides conditions for multiple invertebrates which in turn provide food for other organisms. This measure corrects for the lack of diverse aquatic communities in canals impaired by absence of aquatic macrophytes, lack of exposed coarse sediments, uniform depths, little or no functional riparian zone, lotic habitat has been impacted or eliminated, little to no vegetation or structural shading and shallow refugia along banks, poor connection to floodplains or off-channel ponds, and hard impenetrable banks. The aim of the Dutch study of linear shallows effectiveness was to examine the relationships between the aquatic plant community established after construction with the physical and chemical characteristics of the water body. The system was employed in two navigation canals which experienced about 15,000 boats in 1999, mostly commercial. Not included in prior study, but for possible evaluation would be the use of gravel-like substrates on the landward side of the berms/sheet piles to allow for varying of water depths, development/establishment of fish breeding zones and fish refugia, and expedited functioning of the habitat enhancement method. Artificial islands of floating vegetation within the protected shallow zones may also enhance the method and speed of functionality.



Implementation Factors – Linear shallows are most appropriately located where wave action from navigational traffic is high, and there is sufficient width of the canal and its right-of-way to provide habitat zones approximately 15 to 40 feet in width. Length of linear shallows may vary according to land availability, and one long connected shallow may be created, or a series of separate appendages may be configured. In any case the pile or berm used to separate the linear shallows from the canal should equal the typical maximum wake height, and should have breaks at least every 300 linear feet to allow water circulation (less if fine textured substrate is desired within the shallows). When wake overtops the structure it must reenter the canal through the periodic openings. The openings themselves must be configured with baffled overlaps to minimize wave impact, and the shallows and openings must be engineered to withstand scour during various water level and wave conditions. This measure can be built using standard equipment and products familiar to the construction and navigation industries, though the arrangement and positioning departs from typical marine engineering applications. Construction may be performed by barge or land access depending on cost and other variables. High sediment loads may silt-in the areas over time, necessitating periodic removal of fine sediments. This may set back the natural development of the vegetated shallows community, but also affords an opportunity for nutrient removal from the canal. It may be

useful to oversee the natural succession of the areas and remove vegetative material that develops overly thick root systems that could limit access to the areas by fish, if wake scour does not adequately provide self-clearing. The location of the shallow areas should be closely monitored and in accessible areas to allow for observation of sediment accumulation or floatables blocking the openings or dominating the structure within the shallow refuge area in order to maintain maximum habitat productivity as well as visual appeal. It is best to construct this measure in locations where stormwater inputs and other landward impacts will not affect the stability and function of the linear shallows.

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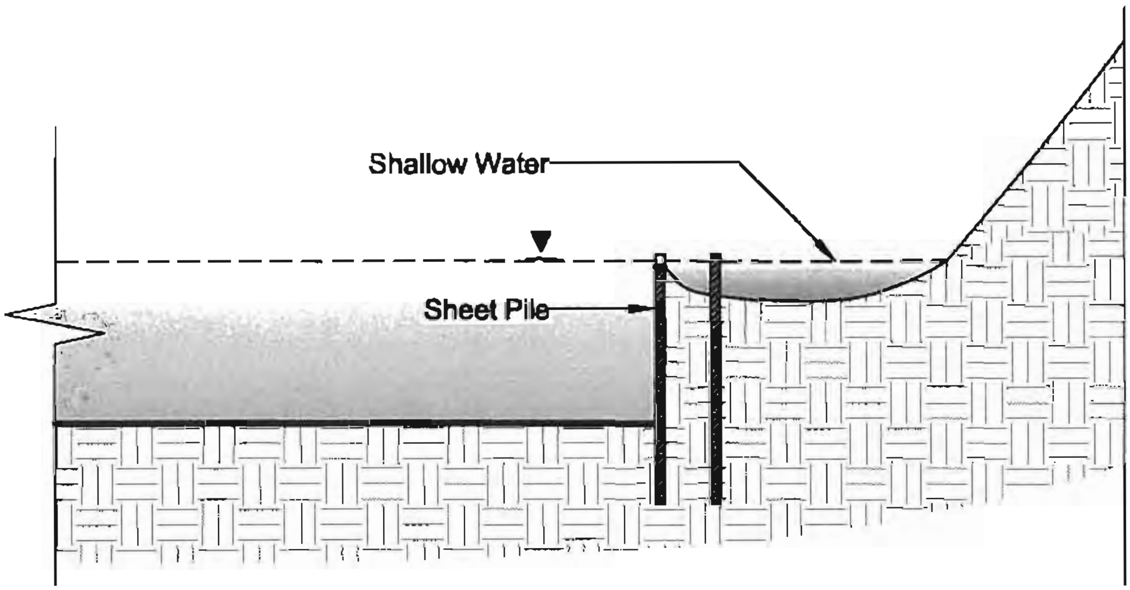

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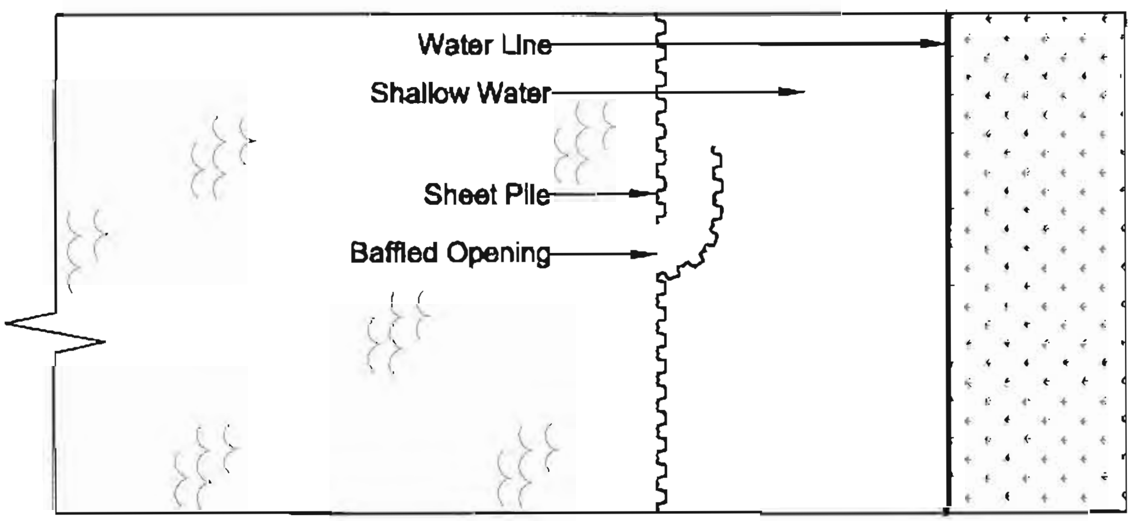


Plan n.t.s.

LINEAR SHALLOWS

Floating Vegetation

DEMONSTRATED USE SETTINGS:

- Rivers/canals
- Lakes/reservoirs
- Water treatment lagoons

MEASURE HIGHLIGHTS:

- Vegetation supported by buoyant structures
- Provides habitat above water for birds, mammals, reptiles, etc.
- Provides underwater root zone habitat for fish and invertebrates
- Scalable by attaching individual units together
- Adjust to fluctuating water levels

BENEFITS PROVIDED:

- Provides fish habitat:
    - Cover
    - Shade
    - Food source
    - Oxygen
- Reduces wave energies
- Improves water quality
- Provides bird habitat
- Can be purchased ready for installation, or "home-made"
- Water column fish refugia
- Bird nesting habitat
- Herptile (turtle) habitat
- Habitat for rooted aquatic and emergent macrophytes
- Protection from wave energy

Method Description – Floating vegetation generically describes the construction and installation of floating elements that support living wetland plant communities. These systems mimic naturally occurring floating masses of wetland vegetation typical in various regions, although they are engineered and contain artificial buoyant materials. While the specific construction materials and techniques of the floating element itself may vary, the concept involves constructing a platform that floats while supporting a mattress of mature, self-maintaining wetland vegetation. These elements are often referred to as Floating Islands. The technique was introduced decades ago in Germany and there are many projects world-wide that have successfully deployed floating vegetation.

A common and tested method comprises of a structural framework of durable, sealed tubing that provides floatation and supports a geofabric reinforced platform of vegetation. The entire unit is typically triangular in design in order to resist high physical forces present due to ice formation, though other shapes are common in ice-free locations. The triangular design also reduces the likelihood that the element can capsize from large wave energies. For simpler applications where space is at a premium, simple tubular modules of coir encased in synthetic mesh attached to buoyant pipes may create linear floating vegetation systems. Additionally an array of round or free-form systems has been created for specific applications.

The tubular floatation elements are constructed of various plastics, such as HDPE and PVC, or metal, such as stainless steel filled with closed cell foam. The tubing elements are joined at the corners using a variety of techniques, all of which allow for flexibility and movement of the individual elements. This allows the overall floating platform to flex with the waves, and allows for a significant function of wave energy dissipation. The vegetated platform varies among individual designs, but is similar in that the platform is suspended between the floating tubular elements. The vegetation is often grown within a nursery setting, within a growth medium such as a coir (coconut fiber) mattress, or a synthetic geotextile, or a combination. It is recommended that the vegetation mat be well established prior to installation and exposure to high energy sites. The floating elements support the mattress such that the green, leafy portions of the vegetation grow above waterline, while the roots dangle below the mattress into the water column.

Habitat Enhancement Values – Floating vegetation units provide both terrestrial (island) habitats for birds, mammals, reptiles, etc, by providing resting, basking breeding and nesting, and grazing habitat. They also provide cover and are ideal for protection from predators and from disturbance by man which typically occurs via land. Floating vegetation also provides unusual and excellent habitat below the waterline for fish. The roots of the vegetation extend down, dangling into the waterbody where they provide physical cover for depths of up to six feet. Simple linear systems create conditions similar to riverine undercut banks, while large systems create expanded areas of floating vegetative cover as occurs in some natural marsh systems. Floating vegetation shades and reduces water temperature while generating locally elevated oxygen levels released into the root zone through photosynthesis, especially during mid-day periods when urban waterways often experience depleted oxygen levels, thus providing a temporal refuge for fish. The physiological activities of the plants and associated microbes provide additional dissolved oxygen to the water column and through associated chemical activity can contribute to an improvement in water quality. Additionally, the dangling underwater root system reduces current and wave energies so suspended sediment begins to settle directly beneath the structure. There are instances where floating vegetation has been observed to root into sediment collected beneath them and over time, and the vegetation anchored and became indistinguishable from natural islands.

Implementation Factors – Floating vegetation is an ideal alternative when banks are too steep for natural vegetation or when trampling by animals or humans occurs (as in urban parks). They are used within the channel environment, in water of any depth, hence requiring no land acquisition and offering a very high degree of flexibility concerning siting. The single largest consideration for the use of floating vegetation is the location. When used in a publicly viewable area, they can provide highly aesthetic greening, improving the appearance and function of otherwise barren steep and/or solid embankments or walls unsuited for vegetation. Unlike other habitat improvement elements that may function underwater or through the establishment of subtle changes in channel form or surface material, floating vegetation offers function combined with recognizable strong visual appeal. When anchored within a navigation channel, the requirements of boat traffic can be addressed to allow passage of boats without obstructing traffic movement. Additionally, it is important that the floating materials not be struck and damaged by passing boats. Wave height is also a consideration as the floating units are susceptible to capsizing if affected by very large waves.

Closely related to this is the anchoring requirement. The floating elements can be anchored to the channel wall or shoreline if placed in close enough proximity, or can be anchored to the channel bottom. Anchoring is achieved by various means and should be carefully considered at the design stage. Buffer systems such as springs, pulleys or buoys help reduce strain and impact on anchors and lines used to secure islands in high energy locations. Floating vegetation may be removed from the waterbody in autumn in order to prune roots and foliage (for nutrient removal via disposal or composting), and to avoid exposure to ice impacts; however this level of maintenance is optional if systems are designed for year-round deployment.

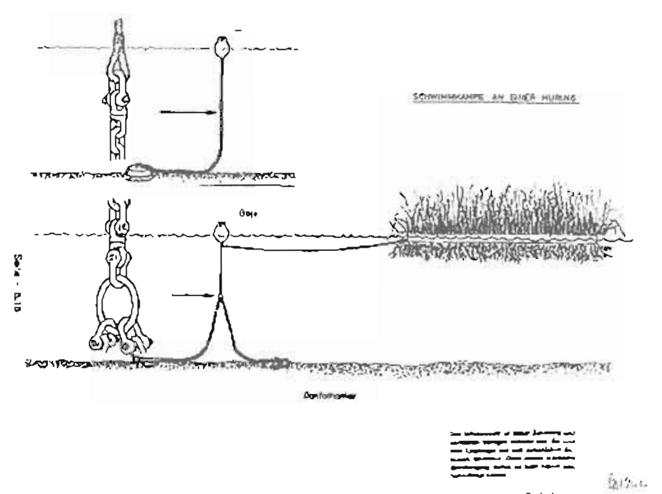
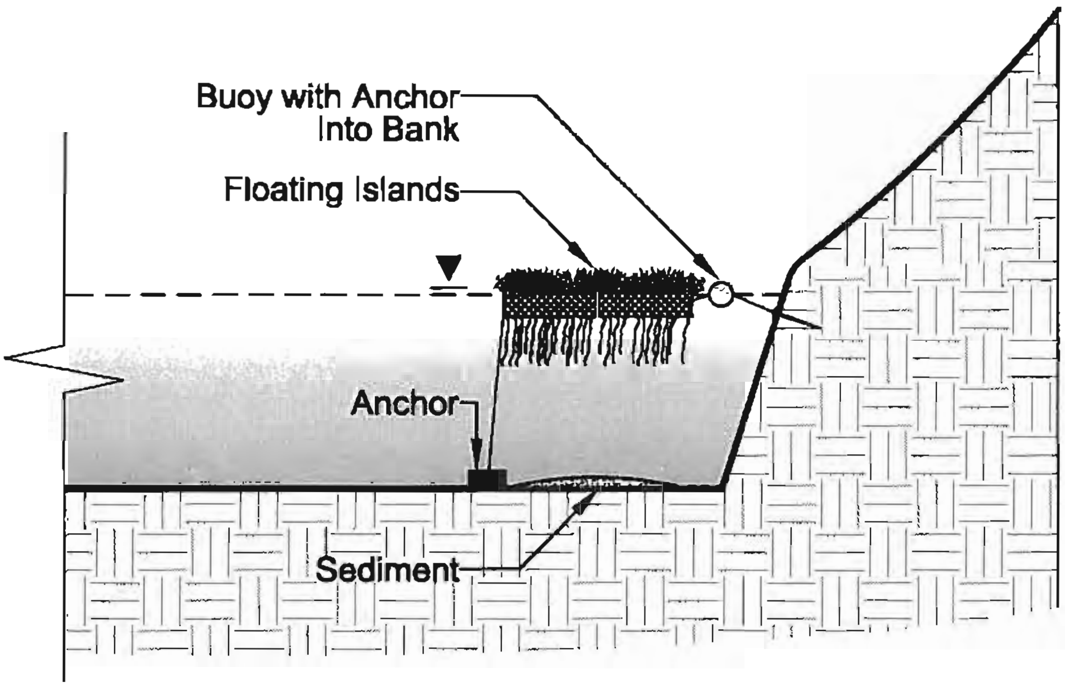


Image Source: Bestmann Green Systems Brochure



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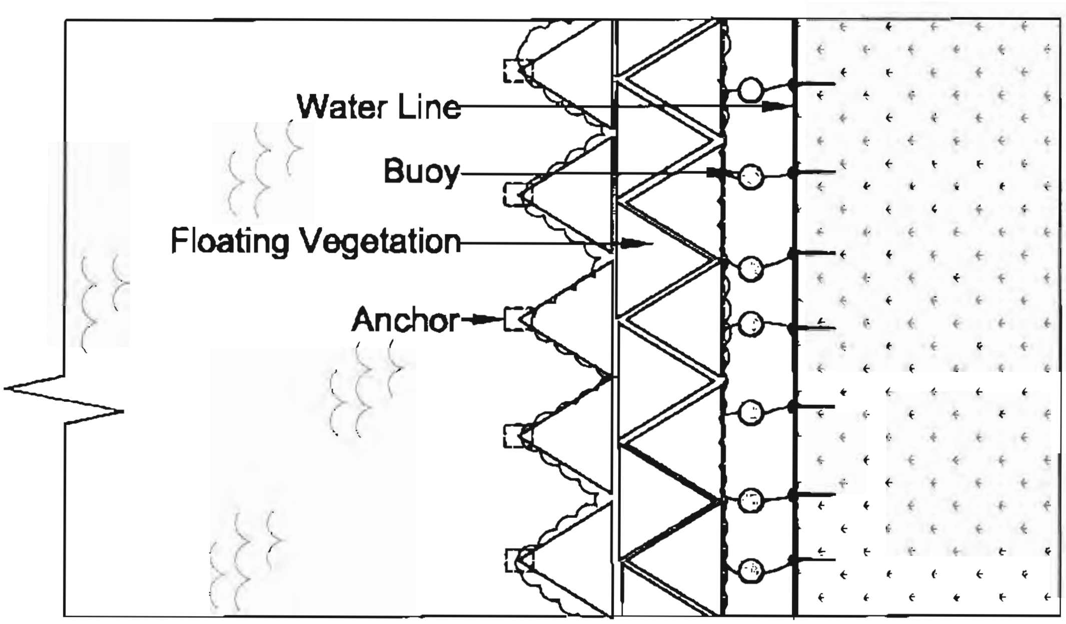
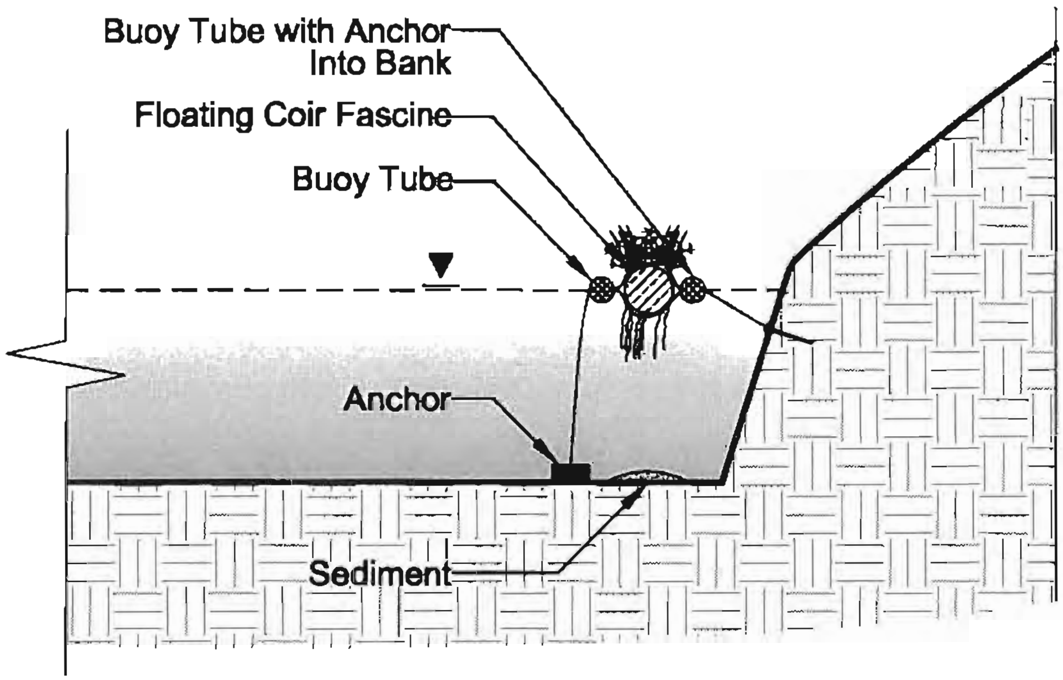


Plan n.t.s.

FLOATING VEGETATION



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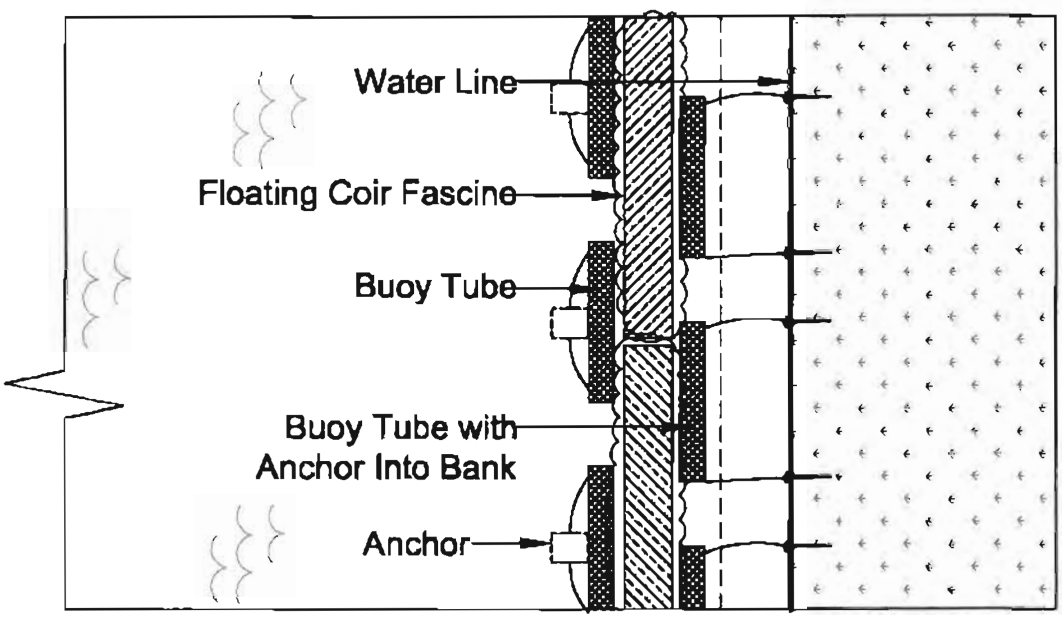

Plan n.t.s.

FLOATING VEGETATION

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Artificial Seaweed

DEMONSTRATED USE SETTINGS:

- Rivers/canals
- Lakes
- Marine environments

MEASURE HIGHLIGHTS:

- Stable mats with buoyant flexible fronds of synthetic polymer that mimics seaweed
- Suited for water quality and depths not tolerated by living vegetation
- Used in aquaculture and natural settings to improve habitat
- Varied size and mounting options
- Prefabricated and easily ordered
- Solid performance record

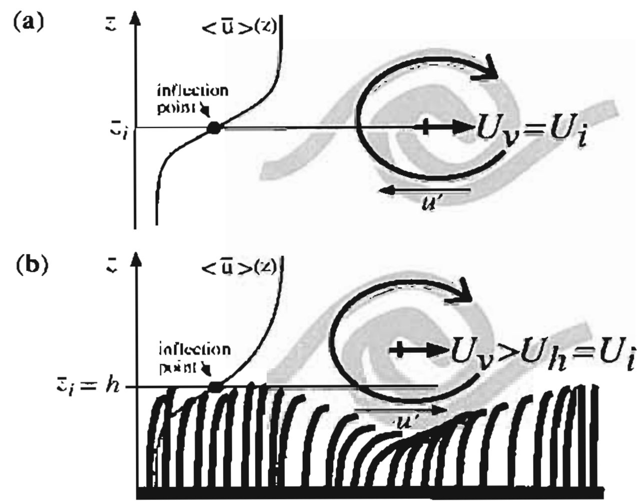
BENEFITS PROVIDED:

- Attenuates wave energy
- Reduces suspended solids
- Consolidates sediment by frond vibration
- Fronds are colonized by algae and microbes
- Provides refugia for fish within and leeward of fronds
- Protection from wave energy

Method Description – Seaweed and other forms of submerged aquatic vegetation play important roles in retaining sediment in high energy waterbodies. However, living plants do not withstand turbid water which blocks sunlight, high sediment loads which chronically abrade foliage, or intense energy levels causing ongoing scour. As a functional alternative based on biomimicry principles, synthetic materials may be use in lieu of vegetation. Artificial seaweed consists of prefabricated mats of high tensile strength woven webbing supporting buoyant fronds. Fronds are made of proprietary polymers designed to withstand high energies in marine engineering applications for a long design life. To ensure stability when placed, mats are either fastened to the ground with anchors or bolts, or attached to interconnected concrete block mattresses which provide mass. Commercially available units typically have options for frond lengths of 2 to 4 feet. Foliage elements cause viscous drag, reducing shear stresses exerted by moving water. Research has shown that kelp beds provide significant sinks for fluid energy and momentum due to elastic deformation of fronds and artificial seaweed works similarly. With reduction of energy in the water column, suspended sediments settle. As sediment builds up, exposed frond length is reduced, the mat creates less viscous drag, and the rate of sedimentation slows until a steady state is reached. Fronds promote formation of gently sloping banks which may extend six feet beyond the mat.

SSCS FRONDED CONCRETE MATTRESS OVER SIMULATED PIPELINE ~ Before attachment of the Safe Net. (150mm Base Blocks)

Habitat Enhancement Values – Artificial seaweed enhances aquatic habitat by creating low energy zones to shelter fish protected from wave energy and flow velocity. Refugia are created both within the fronds, and leeward of them. Additionally, fronds promote formation of sediment deposits with valuable physical properties for a range of macroinvertebrates and other organisms. The sediment bank created is considerably more stable and dense than surrounding unprotected sediments due to consolidation by the vibratory movement of fronds which promote packing and reinforcement. The creation of varied sediment texture and density alone increases habitat value due to suitability for a wide range of organisms, and dense sediments provide needed conditions for burrowing invertebrates. Artificial seaweed has been adapted for use in aquaculture as a means to reduce aggressive interactions and density-related stress due to its high effectiveness in providing resting and hiding areas. Also in aquaculture settings it has succeeded to increase the surface area for the growth of algae and periphyton communities upon which fish graze. Artificial seaweed may be deployed to dissipate energy in highly reflective environments where waves reflect off hard banks (echoing) and cause ongoing resuspension of sediment in order to create conditions fish can tolerate for survival. Or the systems can be deployed in lower energy settings or in combination with other measures in order to create conditions where a wide range of fish species can succeed in growth and reproduction as well.



Implementation Factors – Artificial seaweed is very effective at contributing to habitat enhancement where canal embankments are tall, steep, and or smooth and wave energy is poorly dissipated. Fronds will offer significant energy reduction, yet will tolerate high periodic impacts. Installation techniques depend on bottom substrate and navigational traffic patterns. If the woven mat and anchor system is appropriate then shipping and handling logistics are simple, though commercial divers will be needed for implementation. If the substrate demands concrete mattress for mass, crane barges are needed to bring heavy loads to site. Longer frond length delivers better performance, however propellers must not become entangled. Fronds reduce current velocity and related turbulence in the location being protected and offer significant reduction in sediment resuspension. Artificial seaweed may be used to control sediment transport patterns in order to promote or discourage deposition around other measures. Mats must be effectively anchored so that only fronds move with wave energy and mats remain stable. Performance trials demonstrate fronds perform best in continuous rows, and multiple rows provide substantial overlap of fronds, hence improved function.

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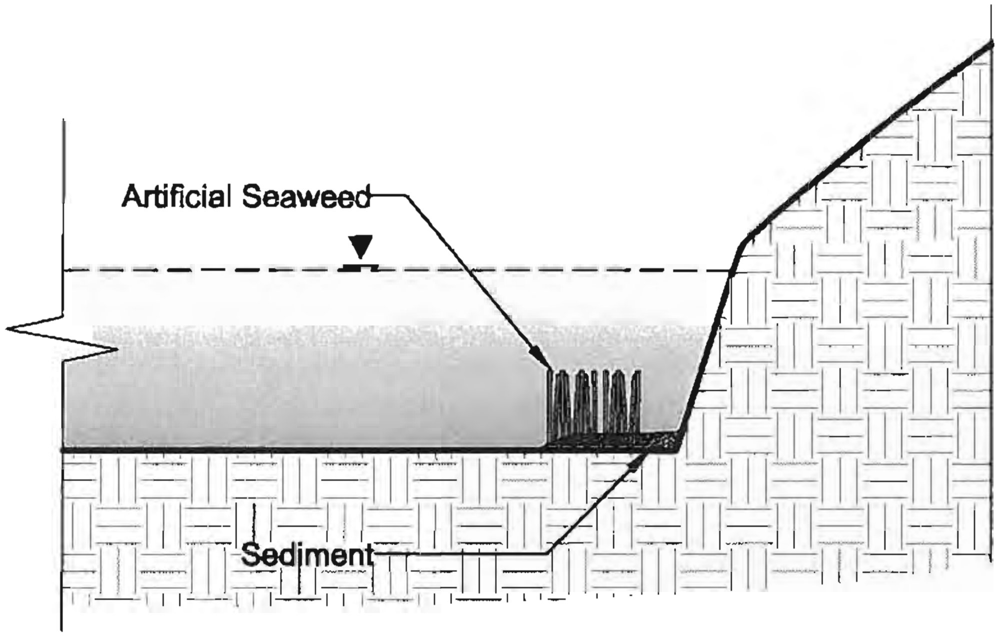

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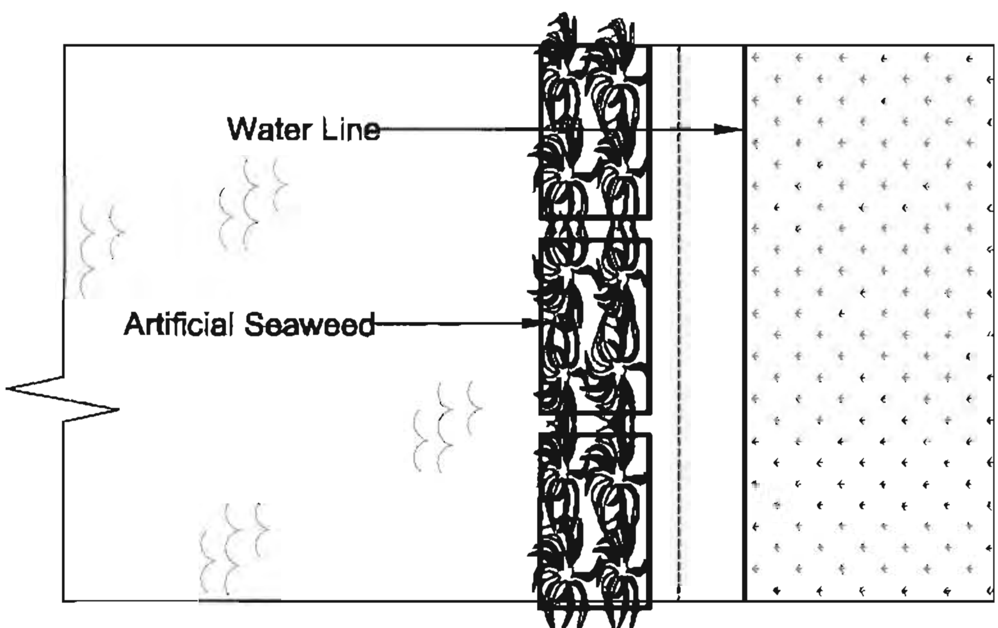

Plan n.t.s.

ARTIFICIAL SEAWEED

Bioengineering GROUP

Chamber Revetment

DEMONSTRATED USE SETTINGS:

- Canals/Rivers
- Ports/Harbors
- Lakes

MEASURE HIGHLIGHTS:

- Rock filled mesh chambers applied to banks of varied slopes
- Suitable for high energy levels and navigation traffic
- Requires no additional right-of-way and does not encroach on shipping channel

BENEFITS PROVIDED:

- Creates overhanging cover for fish
- Increases oxygen levels
- Provides wave energy dissipation
- Interstitial space created for microorganisms

Method Description – Chamber revetments are rock-filled units of various shapes, encased in mesh of various materials and strengths. Typical forms include tubular shapes known as sack gabions, or laminar shapes known as marine mattresses. Mesh is made of woven wire, perforated extruded polymer sheets of high density polyethylene (HDPE) or polypropylene (PP), as well as knotted or interbraided mesh of high strength synthetic yarns. Units may be constructed with any dimension, but are typically 15 ft long, 6-12 inches thick, and various widths. Larger format units typically include interior chambers as well, in order to resist loss of load capacity and deformation over time. Units remain highly flexible and are able to conform to changes in slope angle and irregular bank slopes. Chamber revetments function as consolidated masses of relatively small rock where size and weight of the unit, not the individual stones provide stability, often incorporating graded riprap 5 to 8 inches in diameter, allowing stable yet highly porous coverage of banks in high energy settings. Cavities between stones can be filled with crushed porous stone or other kinds of rock. The porosity and inclusion of in-filled small rock functions in a variety of ways, breaking the organization of a wave and attenuating wave energy; providing capillary and water retention and wicking capacity such as with scoria, thereby creating conditions that permit colonization by microorganisms within voids; and filtering action to protect substrate below. Typical chamber revetments weigh at least 100 pounds per ft².

Image Courtesy of: Triton™, Tensar Earth Technologies, Inc.

Habitat Enhancement Values –Chamber revetment functions chiefly to provide energy dissipation and interstitial voids for invertebrate and bacterial populations, both of which indirectly improve fish habitat. By positioning the units near the normal waterline, both functions can be optimized. In order to create habitat for fish, as well as the invertebrates that are part of the food web, it is critical to provide wave attenuation in heavily trafficked channels. Most aquatic organisms are adapted for exposure to intermittent and low levels of suspended sediment and wave impact. However, within navigation canals there is chronic exposure to sediment abrasion and wave energy and many studies demonstrate that chronic turbidity causes physiological stress and that fish will migrate to seek clearer water. Studies measuring growth rate show that suspended solids also inhibit ability to feed, and young fish grow more slowly in turbid waters as particles adhere to and abrade gill surfaces. Chamber revetments can provide physical habitat near the waterline for fish and micro- and macro-organisms which develop within the rock, especially porous scoria, which provides a complex of interstices that can provide breeding habitat and cover for small organisms. Even small sack gabion type structures provide undercut bank type conditions to shelter fish. Additionally they introduce a compact and cost-effective zone of porous material for wave mitigation and microorganism colonization. Larger marine mattress type systems contribute more to dissipate wave energy, providing reduced sediment resuspension affecting fish. Unlike coarse riprap which does not permit significant colonization by organisms, chamber revetment uses mesh to encase smaller and even porous rocks above and below the waterline in order to provide abundant interstitial space. Wave impacts can serve to prevent sedimentation which blocks and fills void spaces, hence allowing the surface to continue performing ongoing functions that mimic coarse sediment beds in terms of macro and microorganism habitat. Wave impact also can promote alternate wetting and drying cycles within interstitial voids that can develop water quality functions similar to those utilized in trickling media type wastewater systems. Management of water quality, in particular dissolved oxygen level, is critical to allow fish survival, and even fish passage through severely impaired areas, hence linking physical and biochemical processes with fish habitat productivity.

Implementation Factors –Chamber revetments are typically installed on the bank below and above the waterline on banks of virtually any slope. They add value most when deployed on smooth bank surfaces which are devoid of interstitial spaces found in soil and even riprap bank cover. Because chamber revetments protrude no more then 10-12 inches from the channel bank they do not interfere with shipping traffic and hence are suitable for narrow canal areas, as well heavy traffic areas. Many exterior mesh materials used in chamber revetment construction have been applied extensively in marine engineering applications including within shipping lanes where impact by boats, as well as high intensity and frequency of waves are common. Some materials, especially the HDPE types, are highly resistant to impact and abrasion under extreme stress levels. Chamber revetment is highly stable in the face of ice, under fluctuating water levels, and in settings where foot traffic is heavy, though they can be susceptible to vandalism. Compared to other measures, they are the most highly suited for sites with heavy navigation traffic and other physical impacts to the bank zone. However, they lack the benefits provided due to the presence of living vegetation, and also due to wave energy dissipation or refuge creation deeper in the water column. Their impact is largely focused on improving physical conditions through energy dissipation, and though targeted habitat features close to the waterline. Chamber revetments are typically assembled off-site and transported ready for placement. However, their high mass requires a crane barge for placement and depending on the site conditions can require extensive anchoring. On steeper the bank slope, more anchoring is required.

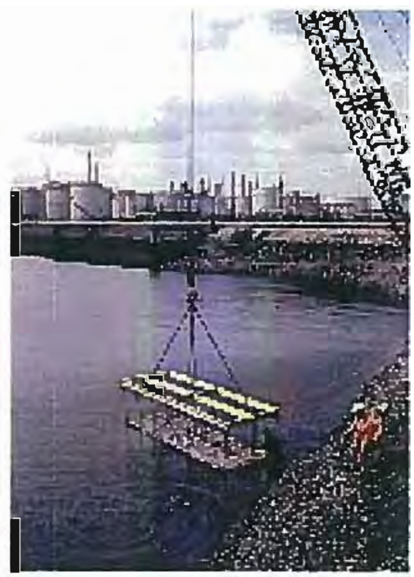

Image Courtesy of: Triton™, Tensar Earth Technologies, Inc.

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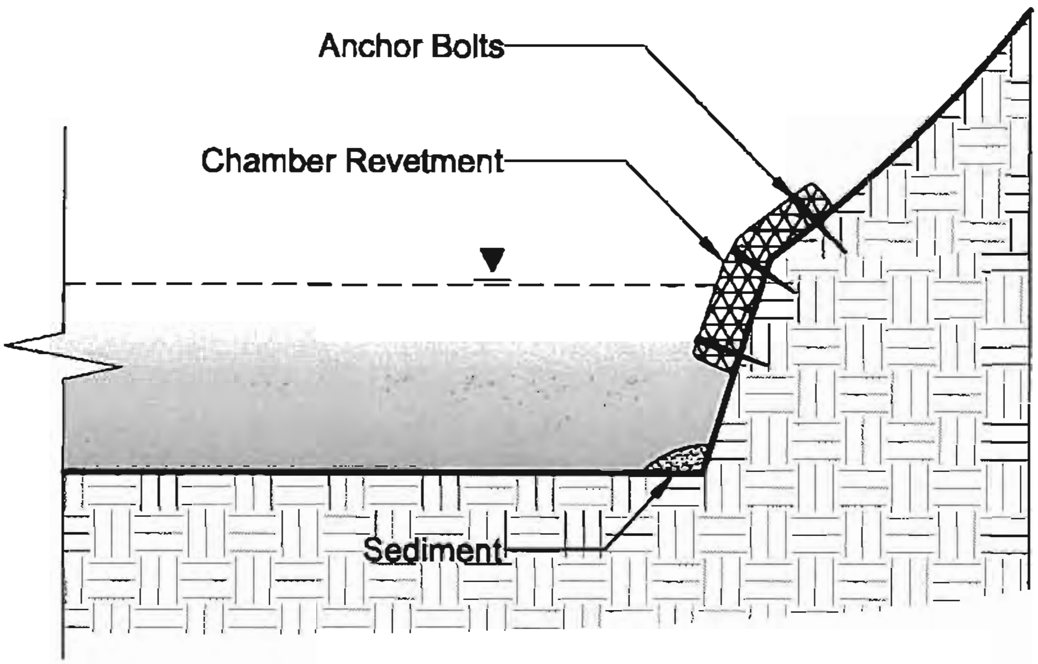

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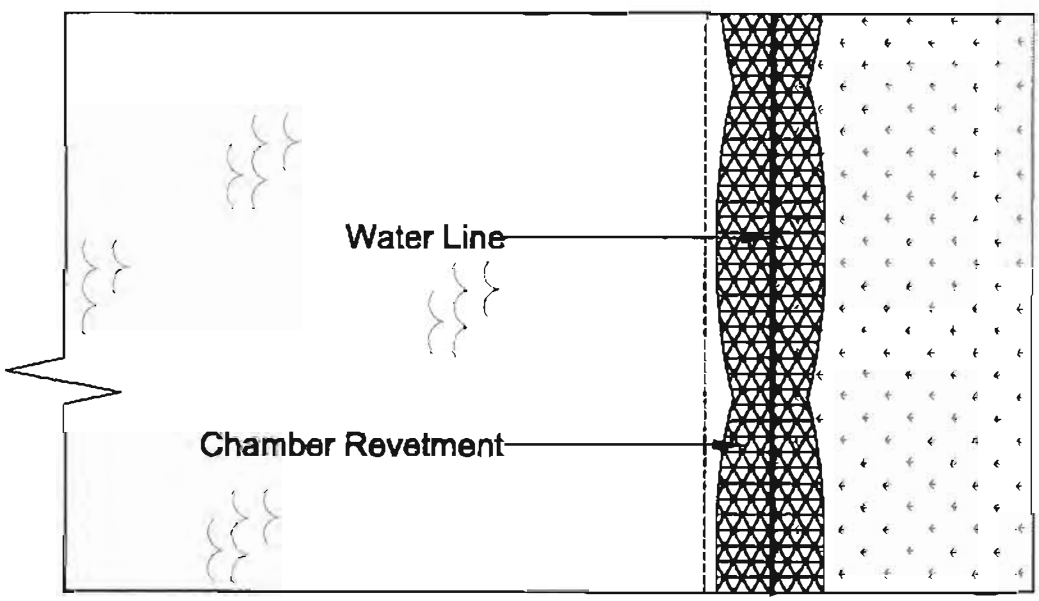

Plan n.t.s.

CHAMBER REVETMENT

Electronic Filing - Received, Clerk's Office, January 6,. 2010
****** PC # 284 *****

Vegetated Revetment

DEMONSTRATED USE SETTINGS

- Canals/rivers
- Lakes/reservoirs

MEASURE HIGHLIGHTS:

- Shoreline vegetation
- Provides habitat above water for birds, mammals, reptiles, etc.
- Can be purchased ready for installation, or "home-made"
- Provides below waterline habitat fish
- Scalable by attaching individual units together
- Immediate protection and revegetation of the amphibic bank zone
- Defines and forms water's edge in urban areas
- Effective solutions in locations where grazing by waterfowl can be a problem

BENEFITS PROVIDED:

- Provides Fish Habitat
  - Cover
  - Shade
  - Food source
  - Oxygen
- Improves Water Quality
- Provides Bird Habitat
- Bird Nesting Habitat
- Habitat for Rooted Aquatic and Emergent Macrophytes
- Protection From Wave Energy

Method Description – Vegetated revetment is an effective way to protect banks from erosion from wave energy. Traditional and tested forms of riprap revetment achieve their primary purpose by weight and the wedging action of stones lying beside and on top of one another. Generally, the heavier and rougher the stones and the thicker the riprap layer, the more effectively it will protect the bank. However, standard riprap is not satisfactory from an ecological standpoint in many applications. Vegetative revetment not only protects banks from erosion and attenuates wave energy, but it also provides a biologically rich habitat above and below the waterline. Vegetated revetment consists of mattress shaped modules that can be constructed in any dimension, but are typically 15 ft long, 6 ft wide, and 6-8 inches thick and are laid on the bank at the waterline. The size and weight of the unit, not the individual stones, serves to provide stability. They contain a fill of graded riprap ranging in particle size from 3 to 6 inches in diameter. The cavities between the stones are filled with crushed porous stone or other kinds of rock. The capillary and water retention capacity of porous rock such as scoria ensures that water is stored and available above the water level, thereby creating conditions that permit colonization by plants and also providing voids for population by invertebrates and microbes. The gradation of the riprap and the use of various fine materials to fill the cavities provide suitable conditions for root development and optimal filtering action to protect the substrate below. Typically, the revetment weighs about 80 pounds per ft² including vegetation.

Placement of individual vegetated revetment modules is easily accomplished when using a crane and requires little manual labor.

The external reinforcement of each module consists of high-strength coarse durable synthetic fiber net which allows handling and transport without difficulty and also ensures shape is retained. Textile layers are added to the standard-type revetment that stabilize the fine materials and serve as filters to prevent migration of bank material. Vegetated revetment remains permanently permeable and no water pressure can build up beneath it due to root action. Vegetated revetments are planted with facultative and wetland emergent plant species depending on position on the bank. Because the wave energies are often hostile to plant establishment, though tolerable to mature stands of plants, it is recommended to use a one or two season growth period in a nursery prior to installation. The protected establishment period allows the roots and rhizomes to penetrate the substrate layers, grow around the various particles and intertwine with one another. Once on site, the established plants will continue to grow outward from providing shade over the water and the roots wherever possible will attached to the substrate or dangle in the water. In this way, the revetment becomes permanently integrated into the landscape, forming a strong visually attractive and somewhat natural-looking bank that offers many habitat functions in addition to reliable armor.

Habitat Enhancement Values – Vegetated revetment provides both terrestrial habitat for birds, mammals, reptiles, etc, by providing resting, basking breeding and nesting, and grazing habitat. It also provides excellent physical habitat below the waterline for fish and micro- and macro-organisms. Emergent vegetation grows within the rock, porous scoria, and fabric matrix. The roots as well as the matrix itself provide a complex of interstices that can provide breeding habitat and cover. The overhanging vegetation provides shade for fish and reduces water temperature. Wave energy is dissipated, providing zones of reduced sediment resuspension and turbulence affecting fish. The physiological activities of the plants and associated microbes provides additional dissolved oxygen to the water column and through associated chemical activity can contribute to an improvement in water quality and fish survival during periods of oxygen depletion. Rather than rough, large-size riprap which does not permit spontaneous colonization by plants, this measure uses mesh and fabric wrapped around smaller rocks with integrated wetland and/or upland plants already established prior to placement. The roots and rhizomes extend into the substrate below after placement, thus ensuring that the revetment is securely anchored in the subsoil, and other anchors may be used on steep banks. Due to the permeability of the revetment layers and the drainage characteristics of the roots and rhizomes formed by the vegetation, vegetated revetments maintain their filtering ability and can be colonized by plants and animals above and below waterline.

When installed on riverbanks and canals, transport and installation is often times best accomplished through the use of a barged equipped with a crane.

Implementation Factors – Vegetated revetments are designed for erosion- prone sites due to wave energies and fluctuating water levels such as canals, lakeshores, and in tidal situations such as tidal rivers or ocean front. The revetment structure permits them to retain moisture for long periods of time and thus provides an environment conducive for plants to grow even if the water level has dropped due to low tide or canal management. Conversely, short periods of high water inundation are typically not a problem for the plants and associated structural materials. The vegetation selected for the revetment depends on an analysis of the site conditions and the intent of the project. Preference is typically given to hardy, native species that can quickly become established and can withstand difficult site conditions including wave energies, floating organics and other debris, variable water quality, etc. The most appropriate form of transport of the modules is by barge. Modules can be temporarily stacked for transport, but should be immediately installed upon arrival to the site. Due to the slab-like construction, the large, relatively heavy modules are most often placed by means of hoisting gear. The angle of the slope on which they are placed should be reduced as much as permitted by local conditions to minimize slippage, or suitable anchors must be used. The design and selection of underlayment is governed by the same accepted geotechnical principles as are used for conventional revetment.

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Experience gained during the engineering works on the Rhine River in Germany led to the development of standard modules for highly impacted banks. The primary application of vegetated revetment was for application on commercially navigable canals and natural waterways in Germany. The highest loads are generated by single vessels proceeding along one side of the canal causing secondary waves up to 1.2 meters high. A significant wave height of 70 cm was assumed for design purposes. Collected data suggests that vegetated revetment's stability against area loads is three times greater than the stability of loose riprap and unlike riprap, significantly attenuates wave reflection due to the elastic deformation of plant stems.

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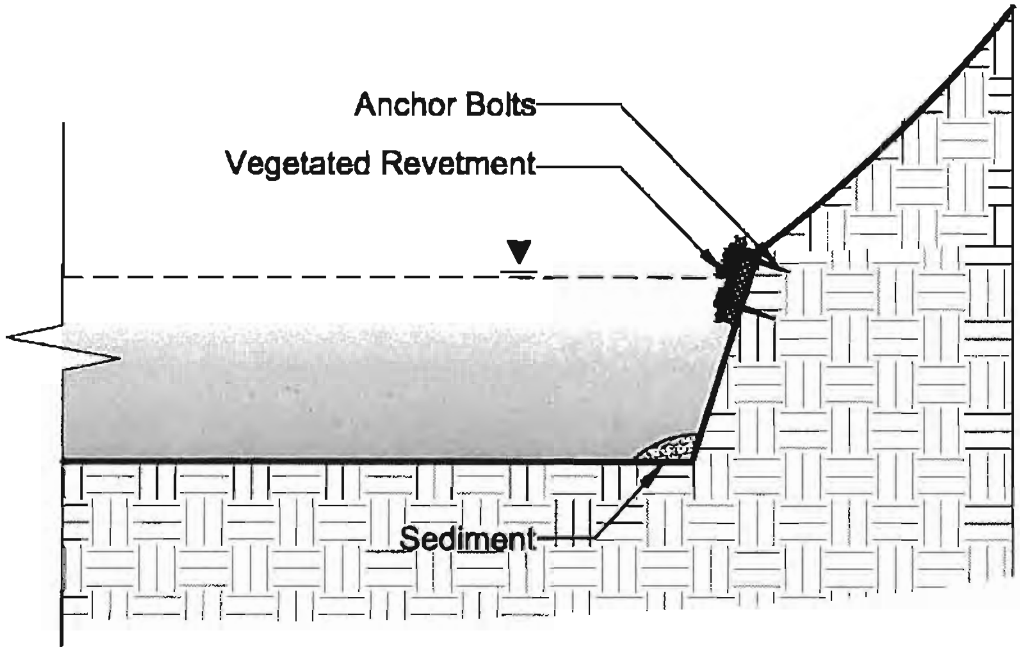

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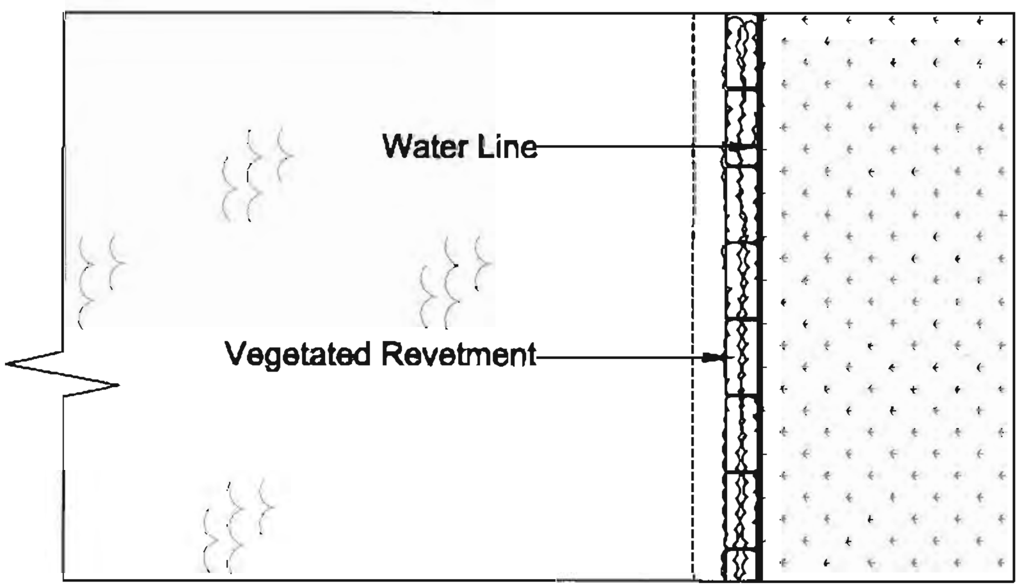

Plan n.t.s.

VEGETATED REVETMENT

Bioengineering GROUP

Sunken Structure

DEMONSTRATED USE SETTINGS:

- Navigable waterways
- Rivers
- Marine environments

MEASURE HIGHLIGHTS:

- Artificial materials resting on waterbody bottom to mimic large woody debris, undercut banks, boulderfields, and other natural in-stream habitat features
- Ability to engineer location, stability, and performance of physical habitat niches, unlike with natural materials
- Many shapes and materials
- Targeted Fish Habitat Enhancement Technique
- Potential for Salvage and Reuse of Recycled Materials
- Placement Equipment Access by barge or Land

BENEFITS PROVIDED:

- Promotes sorting of sediment and variety of substrate for macroinvertebrates
- Protection from waves and suspended sediments
- Provides refugia, ambush points and resting places for fish
- Use by fish and microorganisms, and submerged aquatic plants
- Incorporates green building principles of adaptive reuse of materials

Method Description – Sunken structure describes a broad category of solid, dense materials placed into waterways for the purpose of enhancing physical habitat diversity and type. In aquatic environments, variation of physical form of bed, banks, and naturally occurring debris has long been understood to provide essential physical habitat niches for fish and other organisms. In recent decades, artificial structures have been used to create physical habitat purposefully, as with sinking ships to form artificial reefs in shallow seas. Additionally, structures placed for bank and shore stabilization or other purposes, as well as accidentally placed objects, have been observed to provide effective habitat, often increasing fish populations by as much as 400 percent or more when lack of physical habitat was a key limiting factor influencing ecosystem productivity. Canals and other artificial and heavily managed waterways lack diversity of form and benefit from increased physical structure for habitat, and many types of sunken structure have been used with success. Boats, barges, bridges, and cars have all been used for this purpose, but are not recommended due to the high cost of addressing environmental issues due to contaminants found in paint, fuel, fluids, and other elements combined with the appearance of illicit dumping; however they are effective and affordable.

Structure must be complex in shape to provide a high number of holes and hiding places and be heavy enough to prevent shifting or movement. Additionally, the materials should be chemically and biologically inert, with known mass, dimensions, and lifespan in order to allow responsible and rigorous design. The concept of structure to enhance aquatic habitat is well understood and there are many proprietary structures available, as well as standard non-proprietary designs that have been adopted by public agencies. Examples of these systems include precast concrete units such as jack-shaped elements which perform like large woody debris; perforated hemispheres ideally suited to shellfish colonization; and box culverts which mimic deep hiding cavity conditions found at undercut banks near pools in rivers (often referred to as LUNKER structures). Additionally, recent approaches have sought to divert construction and demolition waste from landfills and repurpose materials for sunken aquatic structure at very low cost. Such materials include bathtubs, toilets, sinks, concrete pieces, catch basins, precast stairs, and clay, metal, or concrete pipes.

Habitat Enhancement Values – Elements are typically clustered, stacked, and where practical connected together to create complex structures. Regardless of material used, research indicates that lines or closely spaced nodes of sunken structure are more effective than single structures for attracting fish. While sunken structure generally offers a similar range of habitat functions, the actual performance for fish habitat enhancement depends on where they are placed, how they are configured, and other variables of the site including most notably water quality. However, there are distinct differences based on the type of measure deployed. High stability concrete jack units are designed to interlock into a flexible, highly permeable matrix. They can be installed either randomly or in a uniform pattern, and the interstices formed provide approximately 40% void space in a uniform placement pattern. The voids provide habitat for fish and other organisms and promote sediment collection, sorting, and stabilization which fosters further habitat enhancement, offering habitat improvements closely analogous to large woody debris present in natural rivers as jams or random pieces. Precast perforated hemispheres provide refugia and resting places for smaller fish species and age classes and offer maximum attachment surface for bivalves and submerged aquatic vegetation. Box culvert type materials, including broken or off-spec items, may be placed directly on the waterway bottom or on a bedding layer of riprap in order to control their depth in relation to water surface and sediment active on the bed (either suspended sediments or loose flocculated materials). Depending on position within the water column, the LUNKER type structures will attract different fish species for use as refugia or ambush points. Additionally coarse sand or gravel may be applied atop a box culvert structure to establish suitable spawning nest material above the zone where sedimentation occurs. Various sunken structure systems made of recycled and salvaged building materials can be configured to achieve forms and functions similar to those mentioned above, based on how they are assembled. The structures generally provide refugia from wake impacts, hiding and resting places for fish in various life stages, and predatory ambush points for piscivores. It is possible and ecologically sound to provide caves and cover for fish by using almost any large heavy structure.

Implementation Factors – Sunken structure is valuable in locations where channel form is devoid of physical variation. Where water depth is adequate to provide clearance beneath shipping traffic, structures may be deployed anywhere within the channel. In shallow water depths sunken structure often offers little value and can create navigational hazards, and hence is not recommended. In intermediate depths, structure can be successfully deployed at channel margins or selected nodes that are clearly marked. Navigational permits may be required at local and/or federal levels although precedent exists for most structures within navigable waterways. The structure must be placed along the bottom of the banks to avoid conflict with shipping traffic. Concrete, porcelain, and metal typically do not incorporate hazardous or toxic compounds and their physical and chemical properties and structural lifespan are well characterized, lending them to engineered applications. Unlike many natural structural elements, most notably large woody debris, these materials have no tendency to float or biodegrade, and exhibit predictable behavior which allows rigorous and responsible engineering procedures called for in urban waterways where public safety and navigational risks dominate. Regardless of what material is used, it can be moved by a crane barge and lowered intentionally into place. Precast concrete hollow mounds with different diameter and shape holes and are intended to sit on the bottom of a waterbody to create habitat. They can be constructed in many different sizes, off- or on-site with an easy-to-use, portable, fiberglass mold either by a certified distributor or by volunteers (after training). They can be easily modified with concrete footers added to increase weight, decrease subsidence on soft bottoms, and accommodate anchoring systems if required. Recycled material will require advanced planning of logistics to find and deliver when required, or coordination with an existing debris recycling program.

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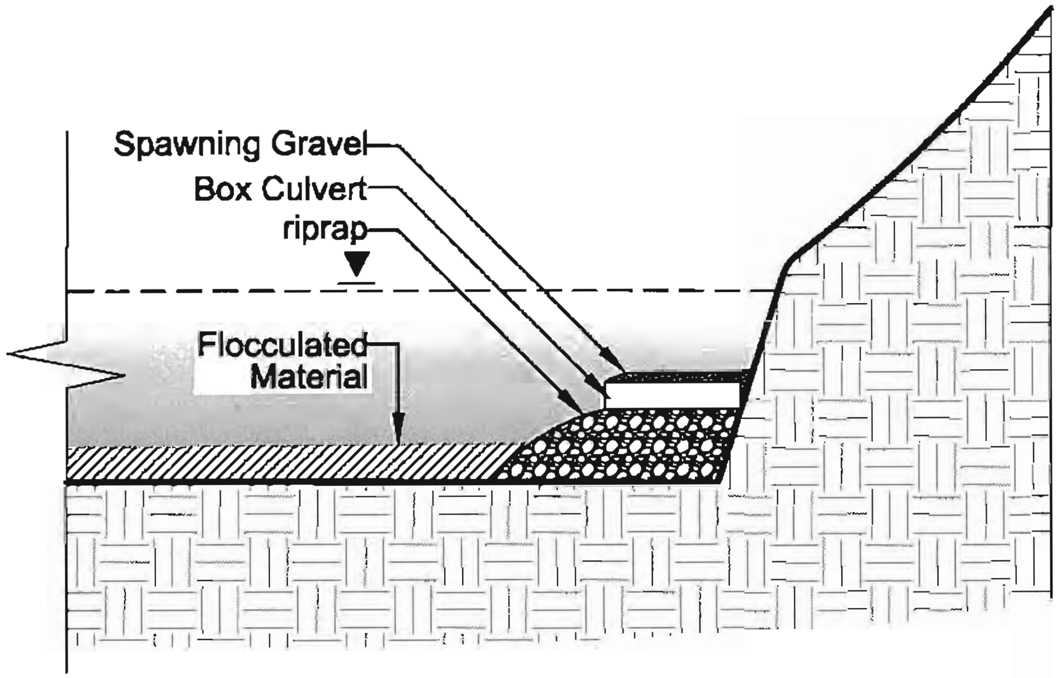

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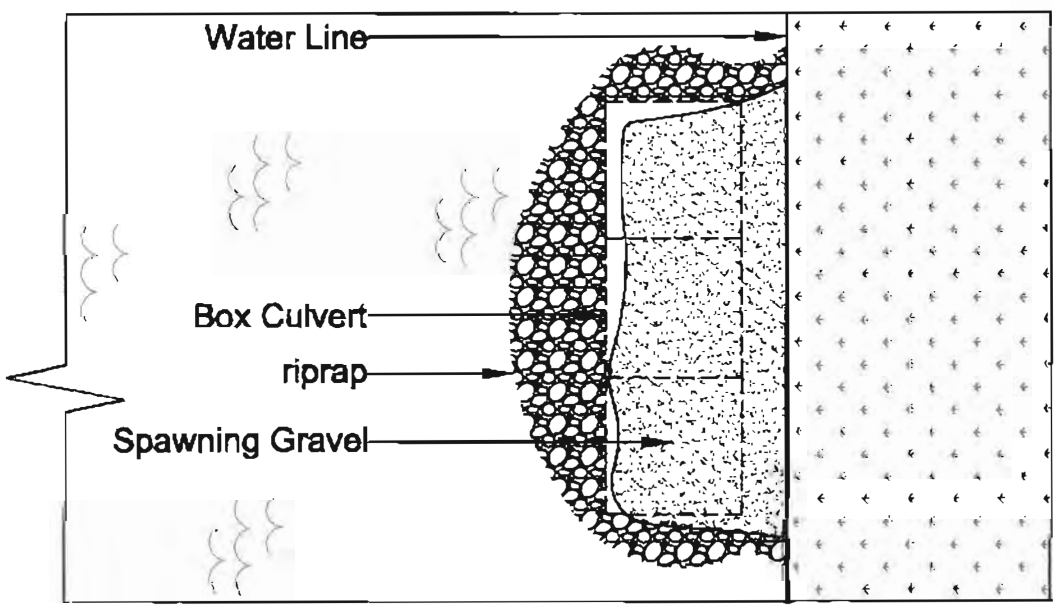

Plan n.t.s.

SUNKEN STRUCTURE

APPENDIX C:

HABITAT IMPROVEMENT CONCEPTUAL DESIGNS

(BIOENGINEERING GROUP, 2009)

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Chicago Area Waterway System

Habitat Enhancement Study

Prepared For:

LimnoTech
Water | Environment | Scientists | Engineers

501 Avis Drive, Ann Arbor, MI 48108

Prepared By:

Building Sustainable Communities on an Ecological Foundation
Bioengineering
GROUP

18 Commercial Street, Salem, MA 01970

BioGroup Project #10055.01

Building Sustainable Communities on an Ecological Foundation
Bioengineering
GROUP

Executive Summary:

Bioengineering Group was tasked with the identification of six measures for enhancing the physical condition of fish habitat on the Chicago Area Waterway System (CAWS). For much of its history the CAWS has experienced heavy commercial vessel traffic producing high energy water movements, a hard/non-living and vertical bank, an unconsolidated sediment bottom, stormwater discharges, sluggish flows and other water quality and ecological challenges. It is believed that establishment of structures within and near the banks to more closely replicate the physical form of a natural river will improve the possibility of fish using and reproducing within the system.

Presented below are four sites and six innovative fish enhancement techniques to achieve a more "natural" and functional habitat for fish within the CAWS. The Appendices attached to this report provide further development of proposed enhancement methods, the application locations within the CAWS, and a detailed Bibliography to directly and indirectly support the methods' reported successes. Finally, the last Appendix includes a cost estimate for comparison purposes.

Sample Site 43

Habitat Enhancement Constraints and Opportunities

The area for enhancement is located along a reach downstream of Sampling Site 43. The heavily navigated but mostly undeveloped location provides an opportunity to improve aquatic habitat within the waterway and to create additional water areas for fish and their food sources adjacent to the waterway. MWRDGC owns significant portions of land adjacent to this reach. Forested lands, as well as vegetated and unvegetated shallow and deep water habitats, currently exist alongside the banks, both on and off MWRDC property. These areas offer proximal variety and diversity of habitats, although linkage and connectivity is currently poor between the waterway and uplands, especially along the north bank. Land surrounding the immediate project site has been used intensively for quarrying, industrial, residential, and storage stockpiling. Barge traffic levels are high and few opportunities exist for public viewing. Restricted access and limited visibility allow for measures that might otherwise be susceptible to vandalism in more accessible locations. Routine dredging maintains navigable depths and passage and the mooring of large barges occurs often within this reach. Habitat enhancement measures must avoid encroaching into navigational channels, and must be highly resistant to intensive boat wake and potential collision.

Site Conditions

This reach of the waterway is characterized by vertical concrete walls in deteriorating conditions on the North bank, with gently sloping vegetated banks, underlain by outcropping limestone, on the South bank. A small building with access stairs exists along the North bank quite near the location of a pond set back roughly 70 feet from the canal. Bathymetric data shows water depths up to 20 feet near the North bank, with a sloping bottom tapering up to the South bank. A wide zone of shallow water insufficient for boat traffic exists along the south bank. This cross section remains fairly constant throughout the reach. Boat traffic has been described as heavy and with frequent barge access and barge docking, making the reach one of the most trafficked segments of the waterways system. Dense bank vegetation exists on both sides of the river, with wide areas of forested land adjacent to banks.

The south bank features a relatively uniform condition of shallow water with overhanging vegetation and unconsolidated sediments. The water's edge features some rough broken stone, some areas of active bank erosion, and some exposed limestone bedrock. The north bank features a concrete wall roughly 10 feet high from the normal water line, with a soil embankment rising an additional height, up to 15 feet in some areas. Many portions of the bank are well vegetated, but some portions show active bank erosion. Due to the height of the bank and the south-facing exposure, little shade is provided and the only overhanging bank conditions are created by gaps in the deteriorating concrete wall. Based on existing information, limiting factors are recognized as frequent very high energy impacts due to navigational barge traffic, riparian vegetation disconnected from north bank, unconsolidated and undifferentiated sediments, poor overhanging bank and shade conditions, and lack of aquatic structure for shelter and other functions.

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Concept Habitat Enhancement Elements

Recommended enhancement measures include those that would cause sediment stabilization and consolidation as well as dissipation of wave/wake energy. Artificial Seaweed along the south bank with Linear Shallows and Chamber Revetment along the north bank have been shown to provide these functions. The mats for seaweed will be placed along the existing 6' contour elevation, parallel to the south bank approximately 50 feet from the bank waterline. In this manner the units should be set back from future dredging and navigational activity, while forming a wide protected zone behind them. A 330-foot-long reach of sheltered shallow shoreline will be created due to the energy dissipation effect of the seaweed. Sediment consolidation, stabilization, and sorting will result, and the overall energy level within the reach will be reduced by placing this element near the middle zone of the channel where it can reduce wave reflection and promote rapid stilling of wake after boats pass by.

Other enhancement measures would include the provision of refugia and shallow water zones for fish fry and possible fish and herptile reproduction areas. Linear Shallows will be excavated in one location at the north bank in proximity to an existing pond, approximately 200 feet long and 40 feet wide at the normal water elevation. The target depth of the Linear Shallows is a range from 3 to 8 feet in order to promote cool heavily shaded low wave energy water conditions with soft, but consolidated, soils and increase particulate organic carbon sources in the form of forest detritus. Due to the high presence of forest vegetation and canopy producing shade, primary producing vegetation is not prioritized, though it may colonize spontaneously. The intent is to protect existing trees adjacent to the concrete wall to conserve canopy cover especially from the southern sun exposure. One water opening with a baffle structure to limit wave impact will be created by removal and modification of concrete wall material. This approach will provide access for fish, herptiles, and invertebrates between the waterway, the Linear Shallows, and/or the nearby pond and forest area.

Upstream and downstream of the opening to the Linear Shallows, Chamber Revetment containing scoria type rock will be attached by bolting to the existing concrete walls in two segments, each approximately 100 linear feet and 18" in diameter encased in vinyl coated galvanized wire mesh. The purpose of the sack gabion type Chamber Revetment is to add a biologically active porous stone medium in the form of an overhanging bank, at and slightly above the typical summer water elevation, but within the wake splash zone. Signage or buoys may be used to indicate the position of Artificial Seaweed and Chamber Revetment elements to navigational users in order to avoid damage to enhancement measures and interference with boat operation.

Habitat Enhancement Outcomes

Selected measures will create reduced energy level zones for fish and related organisms to use as sheltered habitat for various life stages. Measures are located in parallel position in order to attain a protected zone with a high level of boat wake energy reduction, within an active, navigable waterway with harsh wave conditions. The key measures complement each other by providing diverse shallow water and deeper, sheltered water conditions that are accessibly linked for use by not only fish and related aquatic species, but also amphibious and terrestrial animals in order to foster a more complete food web. The main objective is to establish suitable physical conditions in terms of sediment suited for diverse benthic organisms, surface area for algae, microbes, and invertebrates, and sheltered water conditions for varied fish life stages and species. Existing high levels of allochthonous material from adjacent forest leaf litter will then become available for use by a web of aquatic organisms that previously lacked physical habitat. The bank area partially protected by Artificial Seaweed is expected to spontaneously generate some aquatic emergent and/or submerged vegetation due to wave attenuation, which will in turn promote juvenile fish populations and provide well oxygenated daytime refugia for fish during hot weather. In addition, foraging of these artificial seaweed beds by Carp will less of an issue as would be a living, rooted submerged aquatic plant bed. Measures are concentrated within one continuously treated reach 330 feet in length.

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Sample Site 46

Habitat Enhancement Constraints and Opportunities

The urbanized, downtown location of Sample Site 46 provides opportunity to improve fish habitat while also promoting local recognition and understanding for future potential fish habitat measures and outcomes throughout the system. The presence of publicly accessible park areas, residential neighborhoods with focal point water access, and high vehicle traffic on bridges all foster viewing opportunities for visible and appealing improvements as well as fish habitat enhancement measures. Combined with signage to explain and document fish habitat elements, these improvement measures have the ability to not only upgrade the habitat productivity of the channel reach, but also to build support and appreciation for doing so. This level of public involvement often correlates strongly with improved land use management, which in turn contributes to water quality improvements as people become more conscious of personal activities such as car washing, lawn fertilizing, oil dumping, and also larger actions such as conversion of industrial sites to residential or park uses.

Site Conditions

This reach of the waterway is upstream of the actual sampling station. The banks of this reach are characterized by steel sheet pile walls interrupted by short segments of concrete or timber bank structures related to existing bridges or past structures and uses. Stormwater discharge pipes occur at frequent intervals. Although no detailed bathymetry has been provided, depths are understood to be typically 17 feet throughout the reach. Boat traffic has been described as recreational boating, with minor barge access and no barge docking. This makes the reach one of the least trafficked segments of the waterways system, though occasionally used by larger vessels and therefore subject to associated greater wave energies.

Some bank vegetation exists in narrow strips characterized by opportunistic trees, shrubs, and herbs. The resulting plant community is limited in a real extent, lacks structure, and is physically homogeneous providing only small areas of poor quality habitat. The water surface is highly exposed to solar radiation as there is little overhanging vegetation, with bridge decks providing the only significant shade. Based on existing information, limiting habitat factors are recognized as little riparian vegetation of poor quality, limited shade, lack of structure for shelter of various types, unconsolidated and undifferentiated sediments, and infrequent, but high energy, impacts due to boat traffic.

Concept Habitat Enhancement Elements

Recommended enhancement measures include Floating Vegetation and Sunken Structure adjacent to both banks. Elements will be positioned near bridge abutments and within coves, which will serve to provide shelter from boat traffic and which will not impinge on currently observed traffic patterns. Floating Vegetation is to be established using triangular, fabricated modules designed to be highly resistant to ice, boat wake, vandalism, and other impacts expected within the reach. Anchor systems will be designed to address site specific conditions. Specific site conditions, and resulting design requirements, will be more fully investigated and documented during the final design project phase. Floating Vegetation treatments will be assembled in lengths from 18 to 36 feet, positioned in close proximity to the bank, well secured to the bank and bed using tension relief systems such as buoys to minimize stress at anchors. Vegetation shall feature low maintenance species that are tolerant of saturated hydrology and hydroponic type growing conditions, and that create significant underwater root systems for fish shelter, as well as attractive foliage and flowers to enhance public acceptance. The key plant species typically incorporated are *Iris versicolor* (blue flag iris), *Scirpus validus* (soft stem bulrush), and *Juncus effusus* (soft rush).

Sunken Structure will be established at the toe of the sheet pile wall, in areas between floating vegetation zones. Rather than using salvaged materials that may easily be misinterpreted by the public as trash and debris (and hence potentially promote illicit dumping), Sunken Structure will consist of concrete box culvert type units resting on an apron of riprap to lift them above the depths of unconsolidated sediment. The top of the concrete structure will be positioned to allow a minimum 9-foot clearance for boat traffic. Signage or buoys may be used to indicate the location of structures to boaters. The concrete units may be off-spec or damaged materials, making them more affordable, with sizes varying within the range of 2'x3'x4' to 6'x6'x10' according to availability and location. Sunken Structure need not be placed precisely in order to function by providing large shaded and sheltered cavities for fish. Additionally, coarse gravel may be placed on top to offer benthic substrate and/or spawning substrate elevated above the zone of flocculated materials and bedload sediments.

Habitat Enhancement Outcomes

The recommended measures will complement each other by providing a diversity of shallow water and deeper water structural conditions to be used by a variety of organisms. The floating vegetation will also provide additional shade offered by the floating elements themselves as well as the overhanging vegetation. Physical and biological conditions will be improved for a variety of fish species at various life stages, as well as for the benthic invertebrates they depend on as a food source. The presence of underwater root zone shelter and daytime oxygenation will significantly enhance conditions necessary for survival and development of juvenile fish. It is expected that this enhanced reach will also attract mature fish as it becomes a refuge during poor water quality and high boat traffic periods in other reaches. This will thereby help to improve survival and hence quantity and diversity of fish in the waterway system, in general. By treating roughly a third of both banks, a high degree of habitat diversity and productivity will be established, while boat mooring spaces and existing infrastructure will be accommodated. A visually attractive pattern of Floating Vegetation will be established using materials that are compatible with boat traffic. Sunken Structure will be largely hidden, due to poor water clarity. A proposed 1000 linear feet of both banks will be treated, using roughly 300 linear feet of treatment elements on each bank.

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Sample Site 59

Habitat Enhancement Constraints and Opportunities

The heavily navigated, mixed industrial and residential area near Sample Site 59 with MWRDGC owned adjacent land provides for an opportunity to improve fish habitat both within and alongside the waterway. Barge traffic levels are high and some visibility exists from bridge and roadways near the site. A pipe with evidence of a steady base flow discharges immediately west of the bridge-crossing on the south bank, providing some potential for capturing cool base flow water for use in water temperature mitigation. Due to its restricted access and visibility, the site offers the potential for measures that might otherwise be susceptible to vandalism if located in a more central location. Dredging occurs routinely to maintain navigable depths and commercial vessel traffic is heavy. Enhancement measures must avoid encroaching into navigational channels, and must be highly resistant to intensive boat wake and potential collision. Much forested land exists alongside both banks, both on and off MWRDC property. These areas offer proximal variety and diversity of habitats, although linkage and connectivity is currently poor between the waterway and especially the south bank, which has steep vertical banks in many locations.

Site Conditions

Near the sample site, the waterway features well vegetated conditions on the north bank, with relatively stable shoreline conditions in most areas. Heavy navigational traffic is concentrated near the north bank where water depths average roughly 20 feet in the main channel. Bathymetric data shows water depths up to 20 feet near the north bank, with a sloping bottom tapering up to the south bank. A wide zone of shallow water insufficient for boat traffic exists along the south bank. This cross section is typical throughout the reach. On the south bank, conditions are marked as concrete, but appear in images to be natural limestone of relatively low height, ranging up to 5 feet, with a wide shallow zone sloping toward the main navigation channel. Along the south bank riparian vegetation occupies a narrow strip, behind which poor soil conditions support a sparse growth of grass and weeds. However, some emergent wetlands exist in patches near the waterline. In some areas, cavities that formed in the limestone banks appear to provide small lunker-type cavities and overhangs on the south bank. The bottom conditions throughout the reach consist of poorly consolidated sediments and flocculated materials frequently disturbed by boat traffic. The water surface is highly exposed to solar radiation with sparse overhanging vegetation. Based on existing information, limiting factors are recognized as frequent very high energy impacts due to navigational barge traffic, unconsolidated and undifferentiated sediments, minimal overhanging bank and shade conditions, and lack of structure for shelter and other functions.

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* * * * * * PC # 284 * * * * *

Concept Enhancement Elements

Recommended enhancement measures include Sunken Structure, Artificial Seaweed, and Linear Shallows enhanced by a stormwater management wetland designed to intercept and utilize base flow and treat the first flush of stormwater, plus added riparian reforestation. Sunken Structure can be created in at least three possible ways, and the exact method will require further site investigation and assessment of other issues tied to water usage and maintenance patterns, as well as owner preferences. One method would involve improving existing bank cavities or to create new ones. This could be accomplished by divers, possibly in conjunction with a barge, to access the submerged portions of the south bank. Improvement of existing cavities can be accomplished by enlarging them with various tools and potentially reinforcing and stabilizing them with underwater grout. New additional cavities could be created by using a jackhammer to carve cavities into the bank material in new locations. Existing banks of limestone exhibit hard properties capable of holding cavity forms for long periods. A second method is to create aprons of riprap to elevate structures above the zone of unconsolidated sediment and to apply reclaimed material such as toilet bowls and tanks atop the apron to serve as a cluster of cavities for fish shelter. Given the poor public visibility of the site, this measure would not be likely to instigate any illicit dumping and could represent an inexpensive and resourceful solution. A third method is to apply concrete box culverts or pipes atop riprap aprons to create lunker structures along the steepest and deepest sections of the south bank, or alternately positioned a short distance from shore within the wide shallow zone.

On the south bank at both sides of bridge, away from the stormwater outfalls, Artificial Seaweed will be applied on a total of 330 linear feet of bank. The mats for seaweed will be placed along the existing 6' contour elevation parallel to the south bank approximately 50 feet from the bank waterline. In this manner the units should be set back from future dredging and navigational activity, while forming a wide protected zone behind them. Two reaches totaling 330 feet in length of sheltered shallow shoreline will be created due to the energy dissipation effect of the seaweed. Placing Artificial Seaweed elements near the middle zone of the channel where they serve to reduce wave reflection and promote rapid stilling of a wake after boats pass by will initiate additional sediment consolidation, stabilization, and sorting. Overall energy levels within the reach will be reduced.

Linear Shallows and a constructed wetland will provide shallow aquatic habitat and enhance physical characteristics of incoming stormwater. Linear Shallows will be excavated in one location at the south bank in proximity to a stormwater outfall that exhibits base flow, presumably from groundwater discharge along a culverted stream-course. A stormwater management basin will be constructed in order to manage floatables and sediment that are typically carried by urban streams, and also to capitalize on a source of base flow to provide moisture to support hydric soil conditions and percolating flow to the Linear Shallows. The existing culverted stream will be outfitted with a box forebay equipped with a trash screen and a baffle that diverts low flows through an excavated basin planted with wetland species. High flows will continue down the culvert and will discharge to the waterway using the existing apron at the outfall. The constructed wetland will be sized and planted to provide first flush treatment and to infiltrate a significant portion of the base flow that enters it. It is highly likely that the infiltrated water is significantly cleaner than the waterway, and it will serve to flush and maintain cool temperatures within the Linear Shallows.

The area between the stormwater management wetland and the Linear Shallows will be planted densely with riparian trees to promote shade for maintaining cool water temperature. The linear shallows will be approximately 100 feet long and 40 feet wide at the normal water elevation. The target depth of the Linear Shallows is a range from 3 to 4 feet in order to promote cool heavily shaded low wave energy water conditions with soft but consolidated, organism appropriate soils. The intent is to create a cool water sheltered refuge with access for fish, herptiles, and invertebrates. At one end, a water opening with a baffle structure to limit wave impact will be created by removal and modification of bank edge material. The opening to the Linear Shallows will be sheltered by artificial seaweed to further buffer wave impacts to achieve low energy levels. Signage or buoys may be used to indicate the position of Artificial Seaweed and Sunken Structure elements to navigational users in order to avoid damage to enhancement measures and interference with boat operation.

Habitat Enhancement Outcomes

Measures are selected to create reduced energy level zones for fish and related organisms to use as sheltered habitat for various life stages. Measures are positioned in order to minimize impacts to navigation and to establish quiet water zones within an active navigable waterway with harsh environmental conditions. The main objective is to establish productive physical conditions in terms of littoral sediment suited for diverse benthic organisms, surface area for algae, microbes, and invertebrates, and sheltered water conditions and varied fish life stages and species. Redirecting and infiltrating water flowing through the stormwater culvert will maintain water flow and temperature regimes within the Linear Shallows and will allow the establishment of up to five acres of moist soils, which in turn hosts an array of flora and fauna uncommon along the waterways system. Good existing levels of allochthonous material from existing and new adjacent forest leaf litter will then become available for use by a web of aquatic organisms that previously lacked physical habitat.

The bank area partially protected by Artificial Seaweed is expected to spontaneously generate some aquatic emergent and/or submerged vegetation due to wave attenuation, which in turn will promote juvenile fish populations and provide well oxygenated daytime refugia for fish during hot weather. Sunken Structure will increase diversity and quantity of physical fish habitat for multiple purposes depending on design. Measures are dispersed within a reach approximately 1000 feet in length at locations that are best adapted to their installation and ongoing performance.

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Sample Site 99 Bubbly Creek

Habitat Enhancement Constraints and Opportunities

Sample Site 99 is located within a densely urbanized, partially accessible, and somewhat visible area of the city which is undergoing renewal and redevelopment. There is an increased awareness and appreciation of the waterway, which was formerly used for the disposal of slaughterhouse wastewater and other problematic discharges. The site offers opportunity for fish habitat improvement while also contributing to local recognition and understanding for future potential fish habitat measures and outcomes elsewhere in the system. With publicly accessible waterfront areas near old and new industrial and residential areas, combined with very high vehicle traffic on bridges, the site provides viewing opportunities for visible and appealing fish habitat enhancement measures. Signage can be used to explain and document fish habitat elements, thereby not only upgrading local habitat productivity, but also generating support and catalyzing further waterway stewardship in tandem with ongoing development. Bubbly Creek is understood to have high nutrient loading due to its historic use, but is free from commercial navigation owing to its relatively shallow depth. Recreational boat use appears to be on the rise as the area becomes valued as a public waterway.

Site Conditions

The reach of the waterway near the sample site features vertical banks of different materials and in various states of repair. The banks typically have little or no vegetation above the wall structures. There are limited portions of the bank that support vegetation, which is sparse due to erosion at and below the waterline, and these are narrow strips between the waterline and buildings or paved areas. Some newly redeveloped areas of the bank appear to be shallow sloped soil grassy embankments with riprap toe treatment at the waterline. Conditions below the waterline are unknown. Stormwater discharge pipes are located at frequent intervals. Limited bathymetry data has been provided that indicated that depths near the center of the channel are between 9 and 13 feet. Areas along the banks range from 6 to 9 feet. Boat traffic is exclusively recreational and the reach is perhaps the least trafficked segment of the waterways system studied. Aquatic habitat exhibits poor physical diversity and poor productivity. The water surface is highly exposed to solar radiation with little overhanging vegetation, and as with other waterways within the system, bridge decks are the main features that provide shade. Based on existing information, limiting factors are recognized as poor riparian vegetation, poor shade, lack of structure for shelter of various types, unconsolidated and undifferentiated sediments, and infrequent and low-energy impacts from small boats.

Concept Enhancement Elements

Recommended enhancement measures include Floating Vegetation, Artificial Seaweed, Chamber Revetment, and Vegetated Revetment strategically placed to take advantage of existing structures and adjacent land use. To capitalize on existing potentially positive features habitat elements will be position near bridge abutments and within coves, which serve to provide shelter from boat traffic and which will not conflict with existing or likely future boating activities.

Floating Vegetation is to be established using two methods, each suited to the specific location where it will be deployed, in order to minimize cost while maximizing useful life. In areas sheltered from direct ice or boat impact, inexpensive, structurally minimal Floating Vegetation will be assembled from geofabric layers with attached sealed foam filled pipes for buoyancy. In locations along the creek banks, triangular fabricated modules designed to be highly resistant to ice, boat wake, and vandalism will be used. Anchor systems will be designed to address site specific conditions. Floating Vegetation treatments will be assembled in lengths from 18 to 36 feet, positioned adjacent to the bank, and well secured to the bank and bed using tension relief systems such as buoys to minimize stress at anchors. Vegetation shall feature low maintenance species that are tolerant of saturated hydrology and hydroponic type growing conditions, and that produce significant underwater root systems for fish shelter, as well as attractive foliage and flowers to enhance public acceptance. The key plant species used are expected to be *Iris versicolor* (blue flag iris), *Scirpus validus* (soft stem bulrush), and *Juncus effusus* (soft rush), with shade-tolerant *Sparganium* and *Carex* species added in the most shady locations. Artificial Seaweed will be placed between existing bridge piers in order to create sheltered shallow zones passable to fish, but with minimal water circulation shared with the main channel. A visually appealing scattering of Floating Vegetation will be established using materials that are consistent with boat traffic and park access and usage, including fishing.

Floating Vegetation geofabric elements as described above will be added to promote aeration, biological filtration, and physical habitat from the underwater root zone within the sheltered zones. Vegetated Revetment will be applied to the eroding banks with good sun access in the vicinity of the bridge decks. Plant species will include *Carex crinita* (fringed sedge), *Iris versicolor* (blue flag iris), *Juncus effusus* (soft rush), and *Carex stricta* (tussock sedge), and *Leersia* oryzoides (rice cutgrass) Chamber Revetment will be used to treat the shorter eroding bank areas most affected by shade from the bridge decks. Both types of revetment will include polymer mesh chambers rather than wire materials, and will be filled with a rock mix featuring a majority of scoria to maximize porosity because high density rock is not required . To supplement coverage by both types of revetment, riprap toe protection will be applied for bank protection of surfaces deeper than 2 feet below normal summer water elevation. Additionally a small scale mechanical aeration system, potentially powered by photovoltaic cells mounted on bridge structures would complement the proposed bank and in-stream elements in order to provide a consistent level of oxygen in the underbridge areas with high oxygen retention capacity due to high shade, which attracts fish and provides for cooler water temperatures.

Habitat Enhancement Outcomes

Habitat element selection and placement for this reach of waterway have been tailored to take advantage of the unique shaded and sheltered refuge area under the bridge decks, which appears to support greater potential for maintaining cool summer water temperatures compared to other studied reaches within the system. With or without mechanical oxygenation, the proposed measures will help create and maintain shaded, cool water refugia with oxygen levels greater than in surrounding waters. Additional habitat elements have been identified to be placed at intervals on both banks of the creek at dispersed locations in order to promote shelter and physical diversity within the channel upstream of the bridges, and downstream towards the confluence in order to promote migration and access for fish during the various seasons and even throughout the various times of the day. Selected measures serve complementary functions in order to enhance biological and physical diversity for fish and benthic organisms. Within the Floating Vegetation underwater root zones, shelter and oxygenation from photosynthesizing plants greatly enhances survival and development of juvenile fish. The enhancement elements within the reach are also expected to attract mature fish as a refuge during poor water quality and high temperature periods, potentially serving as a crucial resource for fish survival, thereby improving quantity and diversity of fish species. An estimated 200 linear feet of bank in total will receive Floating Vegetation elements of one type or another, approximately 100 linear feet of Chamber Revetment and 200 linear feet of Vegetated Revetment will be applied on the left bank, and an estimated 330 linear feet of Artificial Seaweed will be placed, in a pattern that accommodates boat mooring spaces and existing infrastructure.

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APPENDIX D:

HABITAT IMPROVEMENT PLANNING LEVEL COST ESTIMATES

(BIOENGINEERING GROUP, 2009)

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Bioengineering Group

Chicago River Waterways Study (CAWS)
4/2009 Concept Level Habitat Enhancement Measures Cost

Item Description	Unit Price	Units	Sample Site 46	Sample Site 43(road)	Sample Site 99	Sample Site 59 (road)	
Linear Shallow	Total Cost @ site			$105,825		$53,620	
	119	$/cy					
Floating Vegetation	Total Cost @ site		$83,095		$62,594		
	150	$/sf					
Artificial Seaweed	Total Cost @ site			$101,999	$101,999	$101,999	
	31	$/sf					
Chamber Revetment	Total Cost @ site			$37,494	$18,747		
	94	$/sf					
Vegetated Chamber Revetment	Total Cost @ site				$23,248		
	58	$/sf					
Sunken Structure	Total Cost @ site		$29,391			$29,193	
	122.5	$/sf					
Stormwater Wetland	Total Cost @ site					$109,036	
	51	$/cy					
Solar Aeration	Total Cost @ site				$40,480		
	40480	ea					
	Sub total		$112,485	$245,318	$247,068	$293,848	
	Mob/Demob		$32,000	$38,000	$45,000	$48,000	
	SITE TOTALS		$144,485	$283,318	$292,068	$341,848	$1,061,719

"This cost estimate was developed using available but limited site information, current costs for labor, equipment, and materials, and concept level design of habitat enhancement measures. The development of a more detailed cost estimate based on complete surface/subsurface survey and detailed site analysis and design will represent a more complete and thorough evaluation of total project cost."

IV-1

Chicago River Waterways Study (CAWS)
[illegible] Concept Level Habitat Enhancement Measures Cost Estimate*

Item Description	Unit Price	Regionally Adjusted Price	Unit	Sample Site [illegible]: No. of units	Cost	Sample Site [illegible]: No. of units	Cost	Sample Site [illegible]: No. of units	Cost	Sample Site [illegible]: No. of units	Cost
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total Cost					[illegible]		[illegible]		[illegible]		[illegible]
Est. Unit Cost		[illegible]	[illegible]								
ANCILLARY TREATMENTS											
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SITE TOTALS					[illegible]		[illegible]		[illegible]		[illegible]

[illegible]

This cost estimate was developed using available but limited site information, current costs for labor, equipment, and materials, and concept level design of habitat enhancement measures. The development of a more detailed cost estimate based on complete surface/subsurface survey and detailed site analysis and design will represent a more complete and thorough evaluation of total project cost.

[illegible]-2

APPENDIX E:

SUMMARY OF ESTIMATED COSTS FOR REACH-WIDE HABITAT IMPROVEMENT

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* * * * * * PC # 284 * * * * *

<u>Unit Costs</u>

Vertical Wall Removal:	$3,175	per l.f.
Linear Shallows:	$53,000	ea.
Vegetated Revetment:	$1,160	per l.f.
Bank Pocket Area:	$3,042	ea

Reach	Length (mi)	Bank Length (mi)	Bank Length/ 400 m	Length of Vertical Walls (mi)	Length of Riprap (mi)	Off-Channel Bay				Vertical Wall Bank Removal		Riprap Replacement		Bank Pocket Area Construction				Total Cost
						Current Score	Improved Score	Number Required	Cost	Length to be Removed (mi)	Cost	Length to be Removed (mi)	Cost	Current Score	Improved Score	Number Required	Cost	
North Shore Channel	7.7	15.4	62	0	1.1	2	8	6	$19,698,987	0	$0	1.1	$6,737,280	1.5	20	18.5	$3,486,163	$29,922,430
North Branch Chicago River	7.8	15.6	63	8	5.2	3.5	8	4.5	$14,966,114	4	$67,056,000	2.6	$15,924,480	10.5	13.5	3	$572,666	$98,519,259
Chicago River	1.6	3.2	13	3	0	8	8	0	$0	0	$0	0	$0	0	0	0	$0	$0
South Branch Chicago River	4.6	9.2	37	8	0.4	7	8	1	$1,961,371	4	$67,056,000	0.4	$2,449,920	5	10	5	$562,876	$72,030,167
Bubbly Creek	1.5	3	12	1.3	0.1	1	4	3	$1,918,733	0.5	$8,382,000	0.1	$612,480	9	12	3	$110,128	$11,023,341
Chicago Sanitary and Ship Canal	31.3	62.6	252	16	3.3	4	8	4	$53,383,402	2	$33,528,000	3.3	$20,211,840	12	17	5	$3,830,007	$110,953,249
Cal-Sag Channel	16.1	32.2	130	6	17	2	8	6	$41,188,791	1.2	$20,116,800	8.6	$52,673,280	12	17	5	$1,970,068	$115,948,939
Little Calumet River	6.1	12.2	49	0.6	2.2	6	8	2	$5,201,897	0.6	$10,058,400	1.1	$6,737,280	17	17	0	$0	$21,997,577
									$138,319,294		$205,197,200		$105,346,560				$10,531,908	$460,394,962