CHICAGO AREA WATERWAY SYSTEM HABITAT EVALUATION AND IMPROVEMENT STUDY:

HABITAT IMPROVEMENT REPORT

Prepared for:
The Metropolitan Water Reclamation District of Greater Chicago

January 4, 2010

LimnoTech
Water | Environment | Scientists | Engineers

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Prepared for the Metropolitan Water Reclamation District of Greater Chicago

Prepared by LimnoTech

In conjunction with:

The Bioengineering Group, LLC

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EXECUTIVE SUMMARY

This report documents an assessment of habitat improvement potential in the Chicago Area Waterway System (CAWS) and is the second of two main reports for the CAWS Habitat Evaluation and Improvement Study (the Study). The Study was undertaken, in part, to better understand the current state of aquatic habitat in the CAWS and to identify key habitat impairments, particularly with respect to fish. The habitat improvement part of the Study was intended to meet the following objectives:

- 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 a limited number of the primary habitat impairments in the CAWS, 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.

- There are indications that it may be difficult to measure significant improvements in fisheries as a result of the habitat improvements, even if they can be implemented.

- 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.

1. INTRODUCTION

This is the second of two reports documenting a study of aquatic habitat in the Chicago Area Waterway System. The Chicago Area Waterway System Habitat Evaluation and Improvement Study (the Study) was conducted by LimnoTech under contract to the Metropolitan Water Reclamation District of Greater Chicago (the District). This report documents the habitat improvement portion of the Study. A separate report documents the habitat evaluation portion of the Study.

1.1 REPORT STRUCTURE

This report is structured as follows:

- Section 1: Introduction – This section presents the objectives of the habitat improvement part of this Study.
- Section 2: Summary of Habitat Impairments – Based on the findings of the habitat evaluation part of the Study, this section summarizes the physical habitat impairments in the CAWS.
- Section 3: Potential Habitat Improvement Techniques for the CAWS – This section provides a summary description of potential habitat improvement techniques based on the impairments described in Section 2 and the goals described in Section 1.
- Section 4: Conceptual Designs and Costs for Habitat Improvement –Section 4 describes conceptual designs for example sites in the CAWS and discusses the costs associated with implementation of these designs.
- Section 5: CAWS Habitat Improvement Potential –Section 5 discusses the potential for habitat improvement in the CAWS on a reach by reach basis.
- Section 6: Summary of Findings – Section 6 summarizes the major findings of this part of the Study.

1.2 OBJECTIVES

The Study was undertaken, in part, to better understand the current state of aquatic habitat in the CAWS and to identify key habitat impairments, particularly with respect to fish. The habitat improvement part of the Study was intended to meet the following objectives:

- 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.

The overall emphasis of the Study is on aquatic habitat for fish and, as such, the discussion of habitat impairments and improvement potential in this report focuses on fish habitat. A map showing the CAWS study area is shown in Figure 1-1.

Figure 1-1: The Chicago Area Waterway System Habitat Evaluation and Improvement Study Area

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2. HABITAT IMPAIRMENTS IN THE CAWS

The Chicago Area Waterway System (CAWS) is a system of 78 miles of waterways in and around Chicago, Illinois (Figure 2-1). Approximately 75% of these waterways, by length, are manmade specifically for conveyance of treated municipal wastewater, commercial navigation, and flood control. The portions of the CAWS that were formerly natural streams have been, almost without exception, dredged, straightened, widened, and/or realigned. A brief synopsis of the history of the various reaches of the CAWS was provided in the Habitat Evaluation Report, produced as part of this Study (LimnoTech, 2009). This history is summarized in Table 2-1.

Table 2-1: Construction and Modification History of the CAWS (Greenburg, 2002; Hill, 2000; Solzman, 2006)

Waterway	Length (mi)	Construction History
North Shore Channel	7.7	Completely manmade; excavated 1907-1910
North Branch Chicago River	7.8	Straightened, widened, deepened; 1904 onward
North Branch Canal	1.1	Completely manmade; excavated 1850s
Chicago River	1.6	Mouth modifications; widened, deepened; focus of development since time of first settlement; flow reversed; modifications 1816-1939
South Branch Chicago River	4.6	Straightened, widened, deepened; flow reversed; major straightening in 1928-29; West Fork completely filled in 1920-1930s
Bubbly Creek	1.5	Straightened, widened, deepened, rerouted, tributaries filled; 1860s-1920s
Chicago Sanitary and Ship Canal	31.3	Completely manmade; excavated 1892-1900
Calumet-Sag Channel	16.1	Completely manmade; excavated 1911-1922; widened in 1960s
Little Calumet River	6.1	Straightened, widened, deepened; flow reversed; modifications started in the 1870s

Of the 25% of the CAWS that was originally natural rivers, none have been left unaffected by significant human activity. As shown in Table 2-1, these “natural” rivers have been dredged, widened, straightened, reconfigured, rerouted, and or otherwise modified so they bear little structural resemblance to their original forms. These modifications have been implemented to support uses that are ongoing today, including effluent disposal, commercial navigation, and flood control, so there is little realistic opportunity to undo them without major social and economic impacts.

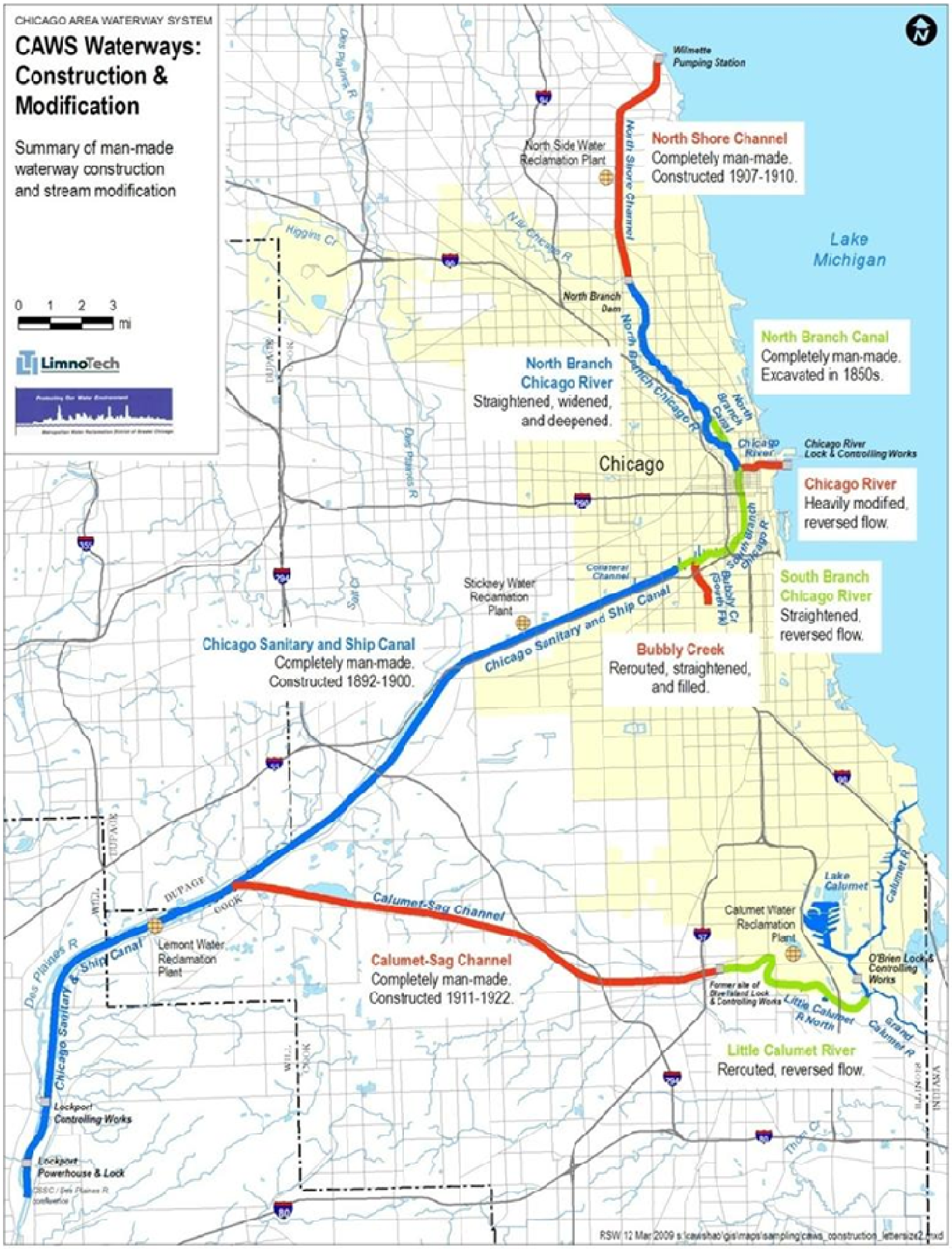

Figure 2-1: Construction and Modification History of the CAWS

Although it may be infeasible to reverse the major waterway modifications that have occurred in the CAWS, it may be possible to improve habitat attributes and functions in the system, however the resultant improvements, if any, may be difficult to measure. By understanding the nature of habitat impairments and their relationship to fisheries, it is possible to conceive of engineered techniques to mitigate adverse impacts of habitat impairments and improve habitat functions. In this Study, the term "habitat impairment" refers to a physical condition or use that appears to be related to fisheries condition in the CAWS, based on the habitat evaluation conducted as part of this Study.

For purposes of evaluating CAWS habitat improvement potential in this report, habitat impairments have been grouped into two categories. First, there are the habitat impairments that have been shown in this study to be most strongly correlated with fish data in the CAWS; these are referred to as primary habitat impairments. In addition, there are other observed habitat impairments that do not show a strong statistical relationship to fish data, but are apparent in the system and would be recognized by most environmental professionals as impairments to aquatic habitat. These are referred to as secondary habitat impairments in this study. The use of the terms "primary" and "secondary" in this study should not be construed to necessarily reflect importance. The distinction is made here solely to differentiate the habitat impairments that were most strongly correlated with fish from those that were not.

2.1 CATEGORIZATION OF CAWS HABITAT IMPAIRMENTS

The habitat evaluation identified the following types of habitat impairment in the CAWS as being most statistically related to fisheries condition:

- Maximum channel depth – The maximum channel depth was negatively correlated with fish metrics in the CAWS.

- Off-channel bays – The presence of larger areas of refuge available to fish that function like off-channel bays was positively correlated with fish data.

- Percent of vertical wall banks in reach – The quantity of vertical walled banks, constructed from steel sheet-piling, concrete, or other materials was negatively correlated with fish in the CAWS.

- Percent of riprap banks in reach – The percent of banks in a study reach covered by riprap was negatively correlated with fish in the multiple linear regression.

- Manmade structures – The presence of manmade structures in the channel (bridge abutments, dolphins, piers) in the channel was found to be an important habitat variable, in a negative sense. An example of these structures is shown in Figure 2-2. It is not clear why these structures are negatively associated with fisheries in the CAWS, but it is likely that it is the anthropogenic uses associated with the structures, rather than the structures themselves, that cause harm.

Figure 2-2: Examples of Dolphin Structures on the Chicago Sanitary and Ship Canal near AWQM 41.

- Percent macrophyte cover in reach – The percent of macrophyte cover in sampling reaches of the CAWS was found to be significantly correlated with fish data in the CAWS.

The six habitat attributes identified above were found to be the most strongly correlated with fish data in the CAWS, using multiple linear regression. In addition to these six attributes, four additional habitat attributes were included in a habitat index for the CAWS to increase the ability of the index to differentiate between reaches and to provide a more robust tool for future evaluation of habitat in the CAWS. These additional habitat attributes are:

- Percent overhanging vegetative cover in reach – This attribute refers to the percentage of each reach covered by overhanging riparian vegetation.

- Quantity of small pocket areas – The quantity of small pocket areas on banks that can provide refuge for fish was identified as an important habitat variable.

- Large deep substrate – The percentage of large substrate (gravel, cobbles, and boulders) was also identified as an important, and limited, habitat attribute in the CAWS. This attribute was characterized by two variables in the index, one representing the deep part of the channel and one representing the shallow part.

- Organic sludge – The percentage of organic sludge on the channel bed represents a general substrate condition in some of the CAWS reaches that indicates very fine sediment with residual impacts of industrial chemicals.

These ten habitat attributes are referred to in this report as primary habitat impairments and are discussed further in Section 2.2. As discussed above, these are not necessarily the only habitat impairments in the CAWS. They represent the impairments that were identified through statistical analysis with fish data and development of a habitat index, using fish data collected between 2001 and 2008. When data for these attributes were used to develop a habitat index for the CAWS and the calculated index values were compared to fish data using linear regression, the index explained 48% of the variability in fish data collected in the CAWS from 2001 – 2008. Because of their strong relationship with fisheries condition and the fact that they apply to large parts of the CAWS, these impairments are categorized as primary impairments in this Study.

In addition to these primary habitat impairments, there are other habitat impairments evident in the CAWS that, while perhaps not as strongly correlated to fish on a system-wide basis, are nonetheless apparent from study of the system. These are referred to as secondary habitat impairments, not because they are less important, but because they were not part of the statistical correlation with fish data. These secondary habitat impairments are discussed in Section 2.3 and include the following, which are either very limited in the CAWS or are absent altogether:

- Channel complexity (heterogeneity) – Variation in the physical form of water bodies.

- Sinuosity – channel plan form characterized by curves, as opposed to straight channels.

- Gradient – Channel bed slope.

- Seasonal hydrologic pattern – Seasonal variations in hydrology, manifested as seasonal variations in water depth and flow.

- Floodplain connectivity – Connection of waterways to their riparian floodplains.

- Tributary access – Relatively unimpeded water access from main channel to tributary waters.

- Submerged structure – Structure below the water surface such as large woody debris.
- Littoral zones – Shallow, nearshore areas of waterways.
- Presence of commercial navigation – The majority of the CAWS is used for commercial navigation and the presence of this commercial boat traffic can have a number of negative effects on fisheries.
- Reduced water clarity – High turbidity is prevalent throughout most of the CAWS and can be detrimental to fish, particularly sight-feeding species.

While the relevance of these secondary impairments has not been quantified in the CAWS, it should, nonetheless, be recognized.

2.2 PRIMARY HABITAT IMPAIRMENTS

As discussed above, ten habitat attributes were found in this Study to be the most significant with respect to CAWS fisheries condition. This does not necessarily mean that these are the only important habitat impairments in the system, but rather they are the impairments whose impact on fisheries in the CAWS can be best quantified using available data. Other impairments, such as those discussed in Section 2.3, may be equally important but their impact cannot be measured with available data. For example, a given impairment may be so extensive in the CAWS that there is not sufficient differentiation from one location in the CAWS to another to support a strong statistical correlation with fish data, such as is the case for sinuosity and gradient in the CAWS.

2.2.1 Maximum Channel Depth

Maximum channel depth was found to be negatively correlated with fisheries condition in the CAWS. In other words, poorer fish communities were generally observed in deeper reaches. While water depth itself is not necessarily detrimental to fish, it is likely indicative of a range of other factors including the lack of littoral zone and the accompanying presence of macrophyte cover, disconnection from riparian areas, and the presence of commercial navigation to name a few.

Deep water reaches in the CAWS can be greater than 20 feet deep to maintain adequate depth for commercial ship traffic (Figure 2-3) and to maintain storage volume for flood flows. These depths are maintained in many parts of the CAWS through dredging by the U.S. Army Corps of Engineers.

Figure 2-3: Barge and Tug on the Chicago Sanitary and Ship Canal. Many CAWS Reaches are Deep Draft Waters (photo taken near AWQM 41, 2008).

The potential to improve this habitat attribute is virtually non-existent. Changing the depth of the CAWS reaches would require partial filling, which would interfere with the primary uses of the waterways, which include effluent disposal, commercial navigation, and flood control.

2.2.2 Off-Channel Bays

Natural waterways provide areas off of, but connected to, the main channel, which provide a variety of value to fish. These areas include riparian wetlands, sloughs, and embayments that create diverse habitats for a wide range of fish species and age classes (Figure 2-4). They also provide spawning areas for many species, that are protected from the higher velocities and shear stresses found in the main channel. They are often the primary reproduction area in natural rivers (Allan, 1995). These areas provide refuge for prey and forage for predatory species. In the CAWS, where the channels are either manmade or significantly modified, these off-channel refuge areas are nearly non-existent. However, there are scattered areas of shelter along the waterways, within the main channels, that appear to provide the same function, albeit on a smaller scale.

Figure 2-4: Example of Off Channel Refuge Found in Natural Rivers, absent from the CAWS (photo taken in Lake Pepin, on the Mississippi River, 2007).

In terms of habitat improvement potential, it may be possible to construct artificial off-channel areas in the CAWS to provide some of the function that these areas provide in natural systems. This may require land acquisition and it would require careful planning to integrate these areas with existing development in more urbanized parts of the system. The presence of infrastructure may also present an obstacle. Nonetheless, this impairment does have some potential for improvement.

2.2.3 Presence of Vertical Walled Banks

The CAWS reaches evaluated in this Study have approximately 65 miles of vertical walled banks, which is about 42% of the banks in the Study area. These vertical walls consist of steel sheet piling (Figure 2-5), stone, and in some cases, wooden walls. The condition reflects the constructed nature of the CAWS and the primary functions of the system for support of effluent disposal, commercial navigation, and flood control. It goes without saying that these vertical wall banks do not resemble natural banks. They reflect the general absence of a littoral zone, disconnection from riparian areas, deep water, reduced in-stream aquatic vegetation and, in many cases, riparian development right to the water's edge.

Figure 2-5: Vertical Wall Banks are found throughout the CAWS (photo taken in South Branch Chicago River, near AWQM 40, 2008).

Naturalization of banks in the CAWS may be technically possible in some areas, but would be very costly. Such naturalization would require removal of existing armoring (sheet piling, riprap, etc.), regrading of the banks to stable angles of repose, planting of the riparian areas, and stabilization to prevent bank erosion. The feasibility of doing this in a given location would depend on a number of factors including existing use and ownership of the land adjacent to the waterway, current use of the bank, and project cost. In theory, however, this attribute has improvement potential. The cost of this type of habitat improvement is discussed later in this report, but it is theoretically possible.

2.2.4 Presence of Riprap Banks

Riprap is graded stone of relatively large size, used to stabilize banks and prevent erosion. Almost 20% of the banks in the CAWS are covered with riprap, based on measurements collected during the Study. On a reach-by–reach basis in the CAWS, the presence of riprap banks (Figure 2-6) varies considerably. It is completely absent in the Chicago River (where the banks consist entirely of vertical walls) and the upper North Shore Channel. In the Cal-Sag Channel and the Upper North Branch Chicago River, more than half of the banks are riprap.

The U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) has conducted research on the impacts of riprap to aquatic ecosystems (Fischenich, 2003). This study included a review of 103 technical publications on the subject, most of which addressed the impacts of riprap on fish species. This literature review concluded that "there is no consensus on the impacts of riprap upon habitat for fish and other aquatic organisms, and the existing publications present conflicting evidence of the nature and degree of impacts" (Fischenich, 2003). This lack of clarity with respect to the impact of riprap makes assessment of the role of riprap in the CAWS more difficult.

Figure 2-6: Riprap Banks in the North Branch Chicago River (photo taken near AWQM 73, 2008).

It is not clear what the negative impact of the riprap is, or if the negative response of fish in reaches with riprap is due to some other factor associated with those reaches and not the riprap itself. The Corps report does state that "In most of the warm water systems studied, coarse hard substrate was very limited, so the addition of riprap provided a habitat niche that was rapidly exploited by a number of species" (Fischenich, 2003). This would suggest that, in a relatively warm water system like the CAWS where coarse substrate is lacking, the riprap would provide some cover for fish, particularly juveniles. But the report also points out a number of inconsistencies in the literature, making definitive interpretation impossible. Lacking such reference information, the CAWS data are taken at face value and riprap is considered in this study to be a habitat impairment.

In general, it may be technically possible to improve the habitat value of riprap banks in the CAWS. Alternatives include incorporating vegetation directly into the riprap or replacing the riprap with bioengineering techniques that use a combination of stabilized earthen structures and vegetation. The improvement potential of any given reach in the CAWS would depend on the ability of the bank modification to provide the stabilization and erosion protection necessary at that location.

2.2.5 Manmade Structures

Manmade in-channel structures were identified in this Study as being negatively correlated with fish in the CAWS. These structures include bridge abutments and piers, docks, dolphins, and other structure that extend into the channel (Figure 2-7). As with riprap, it is not clear from the available data why these structures are negatively correlated with fish or whether it is the structures themselves or some other aspect of the waterways at these locations that is affecting fish. One possible explanation is that these structures simply do not offer sufficiently high structural quality or diversity for fish.

In terms of improvement potential, most of the identified manmade structures in the Study are associated with some function, although some were abandoned and apparently no longer in use. In addition, most are owned by parties other than the District, which poses some challenge. These two qualities make it unlikely that many, if not most, of the structures can be removed. Furthermore, without knowing the specific mechanism of impact to fish that is associated with the structures, there can be no certainty that their removal would have a benefit to fish. For these reasons, manmade structures are not considered an improvable habitat attribute.

Figure 2-7: Manmade Structure Such as Shown Here Were Negatively Correlated with Fish in the CAWS (photo taken in South Branch Chicago River at AWQM 40, 2008).

2.2.6 Macrophyte Cover

Macrophyte cover refers to the measurable presence of submerged or emergent aquatic plants, usually found in shallower water near the banks of waterways. Macrophytes provide cover for fish, habitat for macroinvertebrates, which in turn can provide food for fish, and a source or organic matter to the system. Macrophytes are generally recognized as a desirable aquatic habitat attribute.

The presence of rooted macrophytes is an indication that light penetrates to the bed of the channel and means that these plants are generally found in shallower water. This may explain why macrophyte cover in the CAWS is so limited, since the depths of most of the reaches exceed the depth to which light can penetrate. During the 2008 sampling, measureable macrophyte cover was only found in the North Shore Channel (Figure 2-8), a few stations in the Chicago Sanitary and Ship Canal, the Little Calumet, and at a marina in the Lake Shore Drive sampling reach of the Chicago River. Rooted macrophytes have also been historically observed in the North Branch of the Chicago River.

Figure 2-8: Near-Shore Macrophyte Cover in the North Shore Channel (photo taken near AWQM 35, 2008)

The feasibility of improving macrophyte cover in the CAWS in questionable. To a large extent, this would require increasing the amount of shallow water, littoral areas along the waterways. This is discussed later in this report, in the context of the feasibility of removing vertical wall banks. Aside from this, however, there is likely little opportunity to practically increase macrophyte cover on a sufficiently significant scale to benefit fisheries.

2.2.7 Lack of Overhanging Vegetative Cover

Overhanging vegetative cover was found to be one of the habitat variables most strongly correlated with fish in the CAWS, but it is very limited in most of the CAWS waterways. This variable was measured in the Study as the percent of the channel reach area covered by overhanging riparian vegetation, based on actual field measurements. Overhanging vegetation provides shade and is a direct source of organic matter and insects to the water. The North Shore Channel (Figure 2-9) has the highest percentage of overhanging vegetation in the CAWS, with more than 30% of the channel covered by overhanging vegetation in some areas.

Figure 2-9: Relatively High Overhanging Vegetative Cover in the North Shore Channel (photo taken upstream of AWQM 102, 2008).

Figure 2-10: Low Overhanging Vegetative Cover in the Lower Cal-Sag Channel (photo taken near AWQM 48, 2008)

Parts of the upper North Branch Chicago River have similar overhanging vegetative cover, but in the rest of the CAWS the numbers are generally 10% or less, with some reaches having no overhanging vegetative cover.

The potential for improvement of overhanging vegetation depends on the width of the channel, the degree of overhanging vegetation already present, and the availability of riparian land to support overhanging vegetation. In the North Shore Channel, where overhanging vegetation is already abundant, there may be little opportunity for improvement. In the Cal-Sag Channel (Figure 2-10), where there is little existing overhanging vegetation, there may be more opportunity, but the upper bound of channel area that can be covered may not be as high as in North Shore Channel, because the Cal-Sag is about 2½ time wider than the North Shore Channel. On the whole, however, overhanging vegetative cover is a habitat attribute that can potentially be improved in the CAWS, with some limitations.

2.2.8 Small Pocket Areas in Banks

This habitat variable deals with the relative quantity of small pockets within bank materials that can provide refuge for fish, as measured by actual count in the field. In this Study, bank pocket areas were defined as small (but greater than 1 square meter), semi-protected areas that may serve as refuge from turbulence or as protective cover from predators. These small areas of protection may be available to the transient fishes within reaches of limited habitat structure. Examples are shown in Figures 2-11 and 2-12.

Bank pocket areas represent a potentially improvable habitat attribute because they are located in bank areas and unlikely to interfere with primary uses of the CAWS (effluent disposal, commercial navigation, and flood control). In general, habitat attributes associated with bank areas in the CAWS have more potential for improvement for this reason than do attributes that are associated with the central parts of the channels or with channel beds.

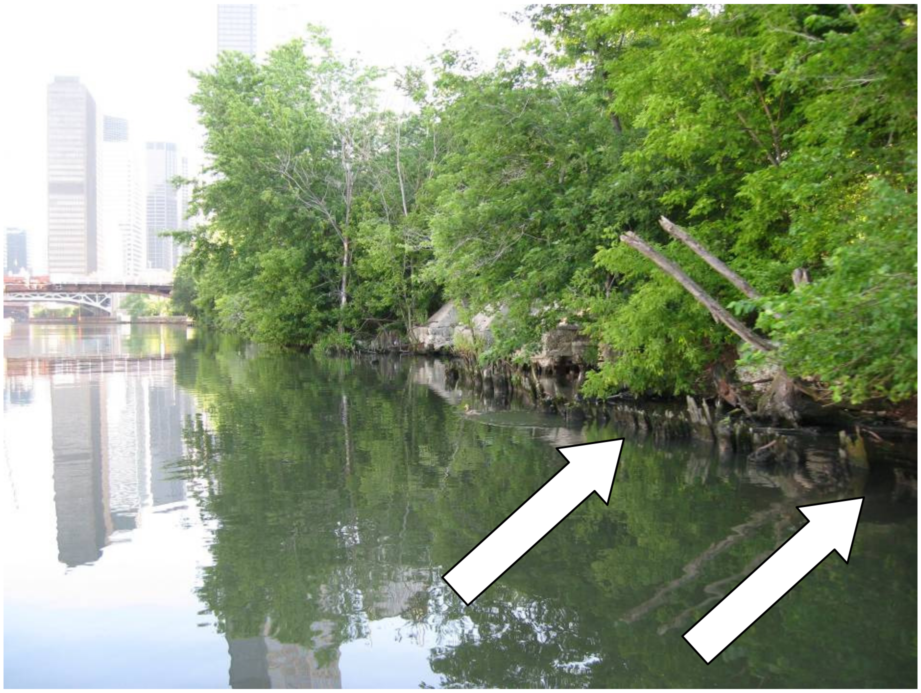

Figure 2-11: Bank Pocket Areas (indicated by white arrows) Created by a Decaying Wooden Seawall on the South Branch Chicago River (photo taken downstream of AWQM 39, 2008).

Figure 2-12: Bank Pocket Areas (indicated by white arrows) Created by a Gaps in Limestone Walls on the Chicago Sanitary and Ship Canal (photo taken downstream of AWQM 41, 2008).

2.2.9 Large Substrate

In this Study, large substrate is characterized as bed material that consists of gravel or larger materials, including cobbles and boulders (Figure 2-13). Large substrate is important to fish because coarse-mixed substrate systems tend to contain highly diverse biota, with strong associations between macroinvertebrate and substrate diversity. Although macroinvertebrate diversity is more strongly associated with coarse substrate than fishes, fishes can greatly benefit from the prey base formed by diverse coarse substrate materials.

Large substrate is generally lacking in the CAWS, where most sediment input is very fine and results in muddy beds. The quantity of large substrate was identified as a habitat attribute positively associated with fish and was included in the CAWS habitat index, so the overall shortage of such substrate is considered a habitat impairment. The Little Calumet River had the highest measured values of large substrate, with samples there containing approximately 25% gravel, cobbles, and boulders on average.

Figure 2-13: Large Substrate, Consisting of Gravel, Cobbles, and Boulders, is relatively Uncommon in the CAWS (photo taken in CSSC, downstream of AWQM 41, 2008).

The feasibility of increasing large substrate depends on a number of factors and must likely be determined on a location-specific basis. In reaches that are dredged to maintain depth for navigation, addition of large substrate is not feasible, as the material would be removed during dredging, if dredged mechanically, or would likely interfere with dredging if dredging was performed hydraulically. In areas that are not dredged, such as the North Shore Channel, it may be feasible to add large substrate.

2.2.10 Organic Sludge

In this Study, the term "organic sludge" refers to a general substrate condition characterized by very fine sediment with residual apparent or measured impacts of industrial chemicals. This type of substrate has been historically observed so frequently, that its measurement is included in the District's routine habitat assessment procedure. Organic sludge in the CAWS (Figure 2-14) is found where chemical impacts to sediment have been measured and sediment often has a petroleum or chemical odor.

Figure 2-14: Organic Sludge is Present in a Number of CAWS Reaches, Such as in This Picture from Bubbly Creek (photo taken at AWQM 99, 2008).

Organic sludge has been found most commonly in Bubbly Creek, where it makes up nearly half of sediment samples collected. It is also found in the Chicago Sanitary and Ship Canal, the Cal-Sag Channel, and elsewhere. It is not clear that organic sludge sediments are directly harmful to fish, but they are likely of direct harm to macroinvertebrates. In addition to the potential for chemical toxicity effects, the sediments may exhibit high sediment oxygen demand, leading to higher than usual oxygen depletion in the lower parts of the water column.

Improving this habitat attribute would require removal of the organic sludge sediments or implementation of some other sediment remediation method. The cost of doing this type of waterway improvement is technically difficult and usually very expensive. Furthermore, the overall extent of these sediments in the CAWS is not known and would require extensive sampling. Because of the uncertain benefit to fish and the technical challenges, improving this habitat attribute is considered infeasible for purposes of this Study.

Preliminary results of the modeling of sediment movement in Bubbly Creek being done by the University of Illinois have indicated that downstream sections of Bubbly Creek experience net deposition after CSO events. Thus, if the organic sediments in this reach were immobilized by capping or removed by dredging, the organic sediment deposits would begin building up again with the first use of the Racine Avenue Pumping Station.

2.3 SECONDARY HABITAT IMPAIRMENTS

As previously discussed, in addition to the primary habitat impairments discussed in Section 2.2, there are a number of apparent habitat impairments that are not necessarily indicated by statistical correlation with fish data, but that most professionals would likely agree are impairments to aquatic habitat. These are described in this section.

2.3.1 Channel Complexity

Variation in the physical form of water bodies is important for aquatic life. Natural water bodies exhibit variability in channel shape, water depth (longitudinally and laterally), sinuosity, and bank condition. The CAWS waterways, on the other hand, have been built to maximize homogeneity which is detrimental to fish. Because channel homogeneity is integral to the primary functions of the CAWS, especially effluent disposal, commercial navigation, and flood control, there is little opportunity for improving this habitat impairment.

2.3.2 Seasonal Hydrologic Pattern

Seasonal variations in hydrology, manifested as seasonal variations in water depth and flow, provide natural triggers for growth and reproduction cycles of aquatic plant and animal communities. There is virtually no seasonal hydrologic pattern in the CAWS because hydrology in the CAWS is almost completely controlled to support effluent disposal, commercial navigation, and flood control. For this reason, there is no potential for improving this habitat impairment. On a long-term, annual average basis, most flow is from wastewater treatment plant effluent, which is relatively steady, and only a small portion of the overall volume of flow is from storm water drainage and combined sewer overflows in response to storm events. Because the hydrology of the CAWS is almost entirely manipulated to support its primary functions of effluent disposal, commercial navigation, and flood control, the potential for achieving a seasonal hydrologic pattern similar to a natural system is nonexistent.

2.3.3 Floodplain Connectivity

Connection of natural waterways to their floodplains is important in the life history of riverine fishes because it offers a seasonal diversity of habitat, as well as an annual input of fine and coarse organic and inorganic material for trophic function. Research has shown that disconnection of natural rivers from their floodplains can lead to lower fish diversity (Reyjol et al. 2008). For this reason, floodplain reconnection is often cited as a goal in stream and river restoration.

Floodplains never existed for the 75% of the CAWS that were excavated where channels did not previously exist (Figure 2-15), such as in the Cal-Sag Channel and the Chicago Sanitary and Ship Canal. In the CAWS reaches that were once natural waterways, or partially so, channelization has eliminated floodplain connectivity almost entirely. In addition to the absence of floodplains and floodplain connectivity, the entire system is actively managed to prevent flooding. For these reasons, there is no potential for improving this habitat impairment.

Figure 2-15: Most of the CAWS Waterways Were Constructed Without Floodplains, Like This Middle Portion of the Chicago Sanitary and Ship Canal (photo taken downstream of AWQM 41, 2008).

2.3.4 Tributary Access

Tributary access in natural systems is important to fish because tributaries typically offer an added range of habitat conditions not available in the main channel. These varied habitat conditions are important for foraging and avoidance of predators. Recent research has shown that the habitat variation provided by tributaries can significantly influence system-wide fish assemblages (Reyjol et al. 2008). In modified systems, tributaries can offer spawning habitats and conditions not found in main channel (Sheehan and Rassmusen, 1998).

A few tributaries are connected to the CAWS, but in many cases, structures have been built across tributary mouths (Figure 2-16). These structures can effectively block fish passage.

Figure 2-16: Tributary Access Blocked by a Concrete Structure at the Mouth of Tinley Creek on the Cal-Sag Channel (photo taken 2008).

Where the structures constructed across tributary mouths serve an ongoing function such as flood control or sediment management, it is unlikely that they can be removed. In some cases, removal of the structures may be possible where they no longer serve a useful function. It may also be possible to retrofit some structures. For example, the District plans to retrofit the dam at the confluence of the Upper North Branch of the Chicago River and the North Shore Channel with a canoe chute and fish passage. In light of this, some potential for improvement of this habitat impairment is possible, but it not possible to determine quantitatively what the benefits to fisheries might be.

2.3.5 Submerged Structure

Submerged structure refers to the presence of structural objects below the water surface within the main channel, such as woody debris, large rock, and manmade materials. This structure provides a variety of functions including refuge from predators, sheltered areas with lower velocities, protection from waves and boat wakes, and forage base for insectivores. The importance of submerged structure is well recognized in natural systems and installation of submerged structure like large woody debris is common in restoration of streams and rivers.

In the CAWS, the presence of submerged structure is counter to the primary uses of the system (effluent disposal, commercial navigation, and flood control). The operation and maintenance of the CAWS includes efforts to remove large objects like fallen trees from parts of the waterways in support of these uses. During the habitat evaluation part of this Study, pilot testing of side scan sonar was conducted to examine conditions below the water surface where visual inspection is not possible due to low water clarity (Figure 2-17). While not conclusive, this effort appeared to reveal the presence of some submerged structure such as automobiles, logs, and rubble. Full characterization of the system was not conducted, nor was ground-truthing to verify the interpretation of the sonar images, however it is apparent that some submerged structure exists. Without complete characterization, it was not possible to quantify the relative importance of this habitat attribute. It is probable, because of operation and maintenance activities in the CAWS such as dredging and removal of fallen trees, that in-channel structure is limited and thus is considered a habitat impairment.

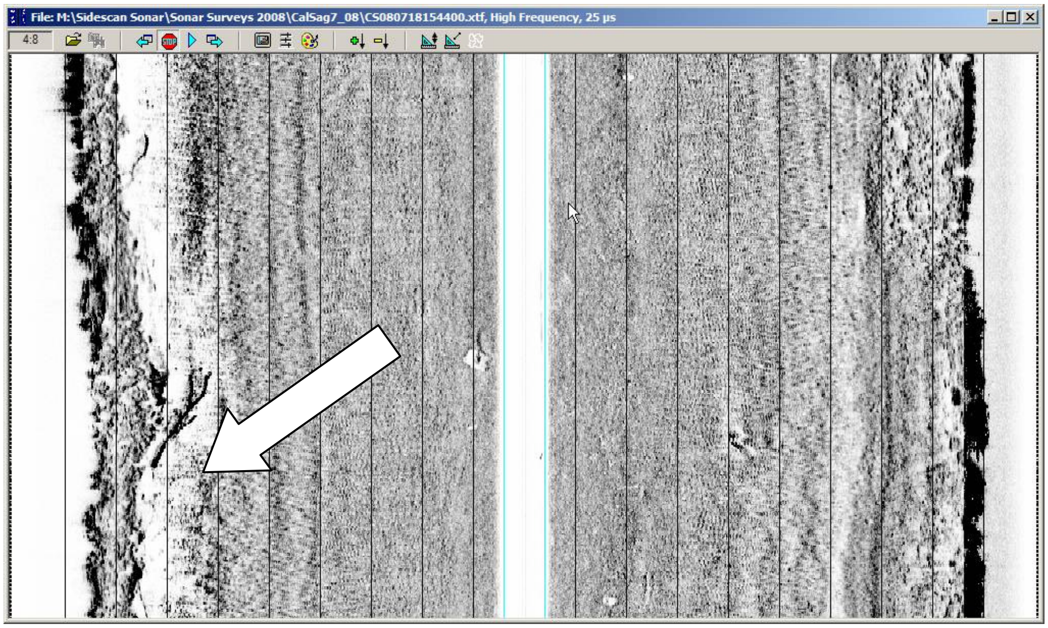

Figure 2-17: Limited In-Channel Structure Exists in the CAWS, Such as the Apparent Tree Trunk Visible on the Left Side of This Side Scan Sonar Image (white arrow) from the Cal-Sag Channel (near AWQM 59, 2008).

Whether this habitat impairment can be improved is uncertain. The potential for improvement would likely depend on the location within the system. The potential for improvement would be higher in reaches that are not used for commercial navigation, such as the North Shore Channel. It may be, however, that sufficient structure already exists there. In other parts of the system, such as the Chicago Sanitary and Ship Canal and the Cal-Sag Channel, the potential to add structure may be limited due to the need to maintain clear passage for shipping.

2.3.6 Littoral Zones

Well-distributed littoral zones, the relatively shallow, nearshore, areas of waterways and water bodies, are important attributes of the aquatic habitat for several reasons. Littoral zones tend to provide greatest floral and faunal diversity of all zones within water bodies. The complexity and extent of this zone is valuable for productivity because the zone experiences daily and seasonal fluctuations in physical and chemical conditions that support system-wide biotic diversity.

In the CAWS, large portions of the system were constructed without littoral zones, such as the Chicago Sanitary and Ship Canal, most of which was excavated into bedrock with vertical sides (Figure 2-18). Other reaches in the CAWS have had their littoral zones replaced with vertical sheet pile walls or other vertical revetments. This is the case in the entire Chicago River, as well as portions of the North and South Branches of the Chicago River, and Bubbly Creek. In total, approximately 65 miles of banks in the CAWS consist of vertical walls made of steel, stone, concrete, and wood, which is roughly 42% of all banks in the system.

Figure 2-18: Many of the CAWS Reaches Completely Lack Littoral Zones by Design, Such as Seen Here in the Chicago Sanitary and Ship Canal (photo taken downstream of AWQM 48, 2008).

Artificial construction of littoral zones in some parts of the CAWS may be feasible on a small scale, at a few locations, by adding rock and soil to the nearshore parts of the channels or by widening the channels and sloping the banks. However, it is unlikely that this could be done on a large scale in the system due to potential interference with primary waterway uses (effluent disposal, commercial navigation, and flood control), interference with current land uses, and the high cost of earthwork on such a large scale. In general, for these reasons, the potential to improve this habitat impairment is limited. However, the potential for replacement of vertical wall banks in the CAWS with sloping, vegetated banks is evaluated later in this report, which would improve this attribute.

2.3.7 Commercial Navigation

While not a physical habitat attribute in the strictest sense, the presence of commercial navigation in the CAWS is, nonetheless, a major aspect of the physical environment in the CAWS that must be considered in the habitat discussion. No new measurements of navigation traffic were collected in this Study. Instead, navigation data collected by the U.S. Army Corps of Engineers (USACE) Waterborne Commerce Statistics Center and subsequently processed for a study by the Great Lakes Fishery Commission (GLFC) were used. These data consisted of total tonnage passing through locks in the CAWS and the GLFC processed these data to yield a record of commercial tonnage passing through each reach annually from 2001 to 2004.

Navigation can be detrimental to fish in a number of ways and there is insufficient data at present to understand the specific ways in which fish are adversely affected by commercial navigation in the CAWS. Effects from navigation can be indirect and direct. Indirect effects can include channel modification (dredging, bank armoring, etc.) to support navigation, resuspension of fine sediments, and subsequent burial of coarse substrate by fine sediments. Direct effects can include injury of fish by ship propellers and adverse impacts from wave forces due to wakes.

This habitat impairment results from a primary use of the CAWS, which is to support commercial shipping. Millions of tons of cargo pass through certain reaches of the CAWS every year, supporting the local and regional economy. As such, it is unlikely that the use of the CAWS for commercial shipping is going to cease in the future. It may be possible to engineer channel improvements to mitigate the adverse effects of commercial shipping traffic, but this would require data on the specific nature of the impacts of shipping on fish, which is not currently available. Because of this, at present, it is concluded that there is no potential for improvement of this habitat impairment, although this conclusion might potentially change in the future if the specific mechanism of impact to fish is identified through additional study.

2.3.8 Reduced Water Clarity

Water clarity, as measured by Secchi depth, is generally poor throughout the CAWS (Figure 2-19). Some reaches, particularly those closest to Lake Michigan, have generally better water clarity, likely due to the inflow of clearer water from the lake. This effect is particularly noticeable in the Chicago River, which has the highest water clarity by far. It is noticeable to a much lesser degree in the upper North Shore Channel, which receives pumped water from Lake Michigan. Throughout the rest of the system, water clarity is almost uniformly poor.

Figure 2-19: Reduced Water Clarity in the North Shore Channel (photo taken near AWQM 102, 2008)

The poor water clarity in most of the CAWS is likely a function of the nature of sediment loads into the system and the use of the system. Most of the flow into the system is treated effluent from wastewater treatment plants and contains relatively little suspended solid material. Most of the sediment load entering the CAWS comes from storm water and combined sewer discharges during wet weather events. Storm water, draining directly to the CAWS or to combined sewers, picks up fine sediment from the urban environment, while sanitary flows in combined sewer discharges may contain fine suspended sediment from waste materials. These sediments enter the CAWS, where a portion remains in suspension and the rest settle. The portion that settles is easily resuspended by passing boat and barge traffic.

Given the nature and sources of the fine suspended solids that contribute to reduced water clarity in the CAWS, there is no practical way to improve this habitat impairment in the near term.

2.4 SUMMARY OF IMPAIRMENTS AND IMPROVEMENT POTENTIAL

The preceding discussion described several habitat impairments, some of which have potential for improvement in the CAWS, and some of which do not. These are summarized in Table 2-2.

Table 2-2: Summary of Habitat Impairments in the CAWS

Habitat Impairment	Basis	Improvement Potential in CAWS
Maximum channel depth	correlated with fish	Not improvable
Lack of off-channel refuge	**correlated with fish**	**Some potential**
Vertical wall banks	**correlated with fish**	**Some potential**
Riprap banks	**correlated with fish**	**Some potential**
Manmade structures	correlated with fish	Not improvable
Lack of macrophyte cover	**correlated with fish**	**Some potential**
Limited overhanging vegetation	**correlated with fish**	**Some potential**
Limited bank pocket areas	**correlated with fish**	**Some potential**
Lack of large substrate	correlated with fish	Not improvable
Organic sludge	correlated with fish	Not improvable
Lack of channel complexity	observed	Not improvable
Lack of seasonal hydrologic pattern	observed	Not improvable
Lack of floodplain connectivity	observed	Not improvable
Limited tributary access	**observed**	**Some potential**
Lack of submerged structure	**observed**	**Some potential**
Lack of littoral zones	**observed**	**Some potential**
High commercial navigation	observed	Not improvable
Low water clarity	observed	Not improvable

As shown in Table 2-2, the habitat attributes that can potentially be improved in the CAWS include off-channel refuge, vertical wall banks, riprap banks, overhanging vegetation, bank pocket areas, tributary access, in-stream structure, and lack of littoral zones. The first six of these are primary impairments and are the focus of the potential habitat improvement methods presented in the next section.

3. POTENTIAL HABITAT IMPROVEMENT MEASURES

As stated in Section 1 of this report, one of the key objectives of this phase of the Study was:

- Given the habitat impairments identified in the Study, determine what physical habitat improvements, if any, can feasibly be implemented in the CAWS.

Identification of potential habitat improvement measures was based on review of habitat conditions in the CAWS, discussion of habitat impairments in the preceding section, review of aquatic habitat improvement projects elsewhere in the Chicago area, and a review of the technical literature. Discussion of these last two sources of information is provided in the subsections below, followed by a description of potential habitat improvement measures. Conceptual designs for selected sites within the CAWS were prepared to provide the basis for cost estimation and planning-level cost estimates were prepared, as described in the final part of this section.

3.1 REVIEW OF HABITAT IMPROVEMENT PROJECTS IN THE CHICAGO AREA

To inform the identification of potential habitat improvement measures for the CAWS a review of relevant habitat improvement projects elsewhere in the Chicago metropolitan area was conducted, to identify useful data where possible. Information was obtained from several local organizations including the following:

- City of Chicago
- Chicago Park District
- Friends of the Chicago River
- Chicago District Corps of Engineers

Although a number of projects were identified, most were recreational improvements or bank stabilization projects and not true habitat improvement projects. No projects were identified in the Chicago area in which biotic data had been collected to assess the impact of the project. Two planned projects were identified that have habitat improvement as a component:

- DuSable Park (Chicago Park District) – Unspecified “submerged habitat” is planned along with a canoe landing.
- Chicago River Walk (City of Chicago) – Unspecified “constructed habitat” is planned as part of a green space/recreational waterfront development.

Several Corps of Engineers bank stabilization projects were identified in the North Shore Channel and the North and South Branches of the Chicago River that involved the use of bioengineering methods for bank stabilization. The Weed Street project, completed on the North Branch and the Cueono Pass project completed on the South Branch, both in 2003, reportedly included construction of lunker boxes along the shore to provide habitat. No monitoring is known to have been performed to assess the benefit of these structures.

The friends of the Chicago River have implemented a habitat improvement project on the Chicago River that they refer to as the “fish hotel”, a floating island design that is intended to provide shelter, forage, and reproduction habitat for fish. A similar structure was observed on the South Branch Chicago River during field surveys in 2008 (Figure 3-1).

Figure 3-1: Fish Hotel, South Branch Chicago River, 2008

Based on a telephone inquiry to the Friends of the Chicago River, it is known that one fish hotel structure is currently deployed in the Chicago River and although periodic visual observations are made to identify fish, no biotic sampling has been conducted to quantify the benefit of the structure.

As a result of inquiries made as part of this Study, no aquatic habitat improvement projects were identified on the CAWS that included monitoring data to measure effectiveness; therefore the identified projects offer little to inform the assessment of habitat improvement potential on the CAWS.

3.2 LITERATURE REVIEW OF HABITAT IMPROVEMENT PROJECTS OUTSIDE OF THE CAWS

An extensive review of the relevant literature was conducted by the Bioengineering Group (Bioengineering), under contract to LimnoTech, to identify case studies, research, or other documentation of successful habitat improvement projects in highly constructed urban waterways. The bibliography of literature reviewed is included as Appendix A.

As a result of this literature review, very little information was identified on the assessment or improvement of aquatic habitat in constructed channels and highly modified waterways similar to those in the CAWS. Some literature addresses habitat in canals in Europe (Boedeltje et al. 2001; Goulder, 2007) but they deal with aquatic vegetation and not directly with fish habitat. Work is planned along channelized sections of the Thames River in London (Francis et al. 2008) but the work has not been conducted so no data are available. Many studies of the impacts of urbanization on urban streams have been published, but these deal with the effects on natural rivers and streams, and not on constructed channels or waterways that have been modified to the extent that the CAWS reaches have been modified.

Although the published literature contains a wealth of information, it is of limited utility in assessing or planning habitat improvement in the CAWS, particularly if decisions are to be based on quantitative benefits to fisheries.

3.3 POTENTIAL TECHNIQUES FOR HABITAT IMPROVEMENT

Based information referenced in the literature review, the nature of identified habitat impairments in the CAWS, and experience in other systems, Bioengineering compiled a set of potential techniques for improving aquatic habitat in the CAWS. These techniques are described briefly below:

- Removal of vertical wall banks – This is not so much a technique as a project type, in which vertical walls are removed and the earth behind the vertical walls is regraded to a stable slope. This results in a littoral zone of varying water depth and presents an opportunity to introduce bank and riparian vegetation. The reduction of near shore water depth may facilitate the growth of macrophytes as well.

- Vegetated Revetment – These are designed like gabion mattresses, but the spaces between the larger stones are filled with crushed stone, stabilized with geotextile and planted with emergent aquatic plants. This is a bioengineering technique that provides vegetation above and below the waterline as an alternative to standard riprap.

- Chamber Revetment – Chamber revetments are similar to blanket gabions and as such are also similar to the vegetated revetment described above, but without the plants. They are an alternative to riprap that can be installed without extending the revetment to the toe of the bank slope, which creates a space below the revetment for cover.

- Sunken Structure – This is a general category of natural or artificial structural materials that are placed underwater to provide shelter for fish. They are either anchored to the bed or held in place under their own weight.
- Floating Vegetation – Floating vegetation refers to an artificial island designed to support plant life, similar to the "fish hotel" concept used in the Chicago River. The floating vegetation provides shade, shelter, forage opportunities, and a source of organic material.
- Artificial Seaweed – Artificial seaweed is a commercially-produced synthetic product that mimics the physical function of macrophytes by mitigating wave and wake energy and providing shelter for small fish.
- Linear Shallows – These are constructed areas along waterways, sometimes constructed behind existing revetment, to provide off-channel habitat.

Illustrated fact sheets describing each of these techniques in greater detail are included as Appendix B.

Table 3-1: Habitat Impairments Addressed by Habitat Improvement Techniques

Habitat Improvement Technique	Habitat Impairments Potentially Addressed
Removal of vertical wall banks	vertical wall banks, lack of macrophyte cover, limited overhanging vegetation, limited bank pocket areas, lack of littoral zones
Vegetated Revetment	limited bank pocket areas, riprap banks
Chamber Revetment	limited bank pocket areas, riprap banks
Sunken Structure	lack of submerged structure
Floating Vegetation	limited overhanging vegetation
Artificial Seaweed	lack of submerged structure, lack of macrophyte cover
Linear Shallows	lack of off-channel refuge

In addition to the techniques described above, removal or modification of structures at the mouths of tributaries may be feasible to address the lack of tributary access, but this approach is limited to the locations where tributaries currently exist and must be evaluated on a case by case basis.

3.4 CONCEPTUAL DESIGNS AND UNIT COSTS FOR HABITAT IMPROVEMENT

Three approaches were taken to further evaluate habitat improvement potential in the CAWS. First, based on the summary in Table 3-1, removal of vertical walls has the potential to counter the greatest number of habitat impairments, so a conceptual design and unit cost was developed for a typical project to remove vertical wall banks in the CAWS. This is discussed in Section 3.4.1. Second, to evaluate the other potential habitat improvement measures discussed above, test sites were selected and conceptual habitat improvement designs were developed for them. This is presented in Section 3.4.2. Finally, conceptual unit costs were estimated for construction of bank pocket areas to address this habitat impairment, as described in Section 3.4.3.

3.4.1 Conceptual Design for Removal of Vertical Wall Banks

Removal of vertical walls has the potential to counter the greatest number of habitat impairments identified in the CAWS; therefore a conceptual design was developed specifically to examine this approach to habitat improvement. The design is illustrated in Figure 3-2 and would involve the following major elements:

- Stabilization of the existing wall and excavation of earth and rock from behind the wall to create a sloped bank.
- Installation of bioengineering bank stabilization around the waterline to prevent future erosion.
- Removal of the existing vertical wall, down to the bed of the channel.
- Planting of riparian vegetation at the top of the new bank.

Although this project concept is relatively simple and is possible from an engineering perspective, there are a number of complicating factors that should be recognized up front. These include the following:

- The project would involve the widening of the channel, which would require acquisition or riparian land along the waterways. Much of this land is currently owned by parties other than the District and may currently be in use by the owners or not available for acquisition.

- There are likely utilities and infrastructure present along parts of the CAWS that would interfere with this type of project. These would have to be relocated.

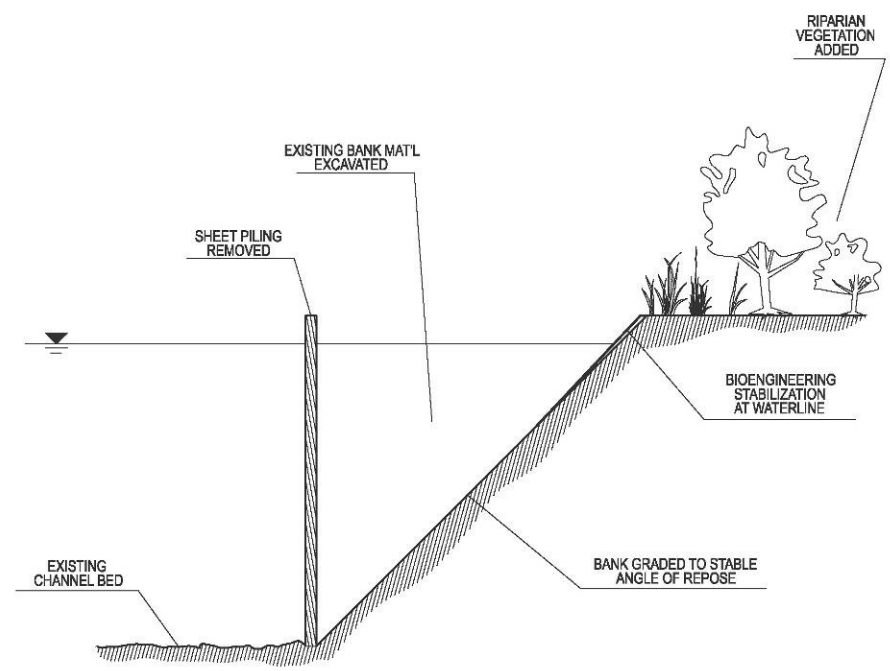

Figure 3-2: Conceptual Design (Profile) for Removal of Vertical Wall Banks

- Some of the riparian land that would be taken by this type of project may have structure built on it, which would require demolition.

- Much of the CAWS exists in areas that have been urbanized for over a century. It is possible that some of the land along the CAWS has been contaminated by release of petroleum and industrial chemicals in the past. This contamination might be exposed by a project of this type, which would complicate the project.

There are other potential complicating factors associated with this type of project, but these are the major ones. Each would have to be addressed before this type of project could be implemented. Because the costs for these items would be driven by location-specific conditions, they cannot be accurately estimated with available information as part of this analysis.

A construction cost estimate was prepared for this conceptual design, including the project elements outlined above. These estimates are not intended to include all project elements and should be viewed as preliminary, planning level estimates that may reflect the lower bound of project costs. Also, because the project cost is a function of the channel depth (i.e. the deeper the channel, the further away from the vertical wall the excavation must extend) and the CAWS channels vary in depth, conceptual cost estimates were prepared for a range of typical depths. Costs were estimated on the basis of a project involving 500 linear feet of bank. These were then used to develop a lumped unit cost per linear foot of bank. The estimates are summarized in Table 3-2.

Table 3-2: Conceptual Unit Cost Estimates (per linear foot of bank) for Removal of Vertical Wall Banks in the CAWS

Project Element	**Channel Depth**		
	15’	20’	25’
Mobilization/ Demobilization	$84	$112	$142
Earthwork[1]	$743	$1,170	$1,685
Bioengineered Bank Stabilization	$35	$35	$35
Riparian Vegetation	$56	$56	$56
Sheet Pile Extraction[2]	$860	$968	$1,075
Design/Oversight/ Contingencies	$710	$834	$900
Total	**$2,488**	**$3,175**	**$3,893**

The estimates presented in Table 3-2 suggest that the cost of removing vertical wall banks in the CAWS, which would improve several habitat impairments, would be between $2,500 and $4,000 per linear foot of bank, not including costs for land acquisition, demolition of structures, relocation of utilities and/or infrastructure, and environmental remediation, if needed. It is conceivable that these other factors could easily double the project costs. Implementation of this project concept is discussed further in Section 4.

[1] Cost estimates assume soil excavation; cost for excavation of rock will be higher.
[2] Costs were estimated for removal of steel sheet pile walls; cost for other materials will vary.

3.4.2 Conceptual Design Sites

To illustrate the other potential habitat improvement techniques described above and to provide the basis for developing planning level cost estimates, four sites were chosen to develop conceptual designs for habitat improvement in the CAWS. Each of the four chosen sites exhibits a number of the habitat impairments identified in the CAWS. Locations were chosen where District monitoring has historically been conducted to provide a baseline of existing physical and biotic conditions in case the decision is made to pilot test any of these techniques or conceptual designs. The sites are summarized in Table 3-3.

Table 3-3: Summary of Site Habitat Improvement Techniques

Site Description	Habitat Impairments at Site	Habitat Impairments Addressed by Conceptual Design
Cal-Sag Channel at Route 83 (AWQM 43)	limited bank pocket areas, limited "natural" banks, riprap banks, lack of in-channel structure, limited overhanging vegetation, lack of off-channel refuge	limited bank pocket areas, riprap banks, lack of in-channel structure, lack of off-channel refuge
North Branch Chicago River at Grand Avenue (AWQM 46)	limited bank pocket areas, limited "natural" banks, lack of in-channel structure, limited overhanging vegetation, lack of off-channel refuge	lack of in-channel structure, limited overhanging vegetation
Cal-Sag Channel at Cicero Avenue (AWQM 59)	limited bank pocket areas, limited "natural" banks, riprap banks, lack of in-channel structure, limited overhanging vegetation, lack of off-channel refuge	lack of submerged structure, lack of off-channel refuge
Bubbly Creek at Archer Avenue (AWQM 99)	limited bank pocket areas, lack of in-channel structure, lack of off-channel refuge	limited bank pocket areas, lack of submerged structure

A map of these sites is presented in Figure 3-3. Detailed descriptions of the conceptual design and concept plan view drawings are included in Appendix C. It should be noted that these designs are provided to illustrate how the potential habitat improvement techniques can be used in the CAWS. The scale of implementation and quantity of these techniques can vary substantially.

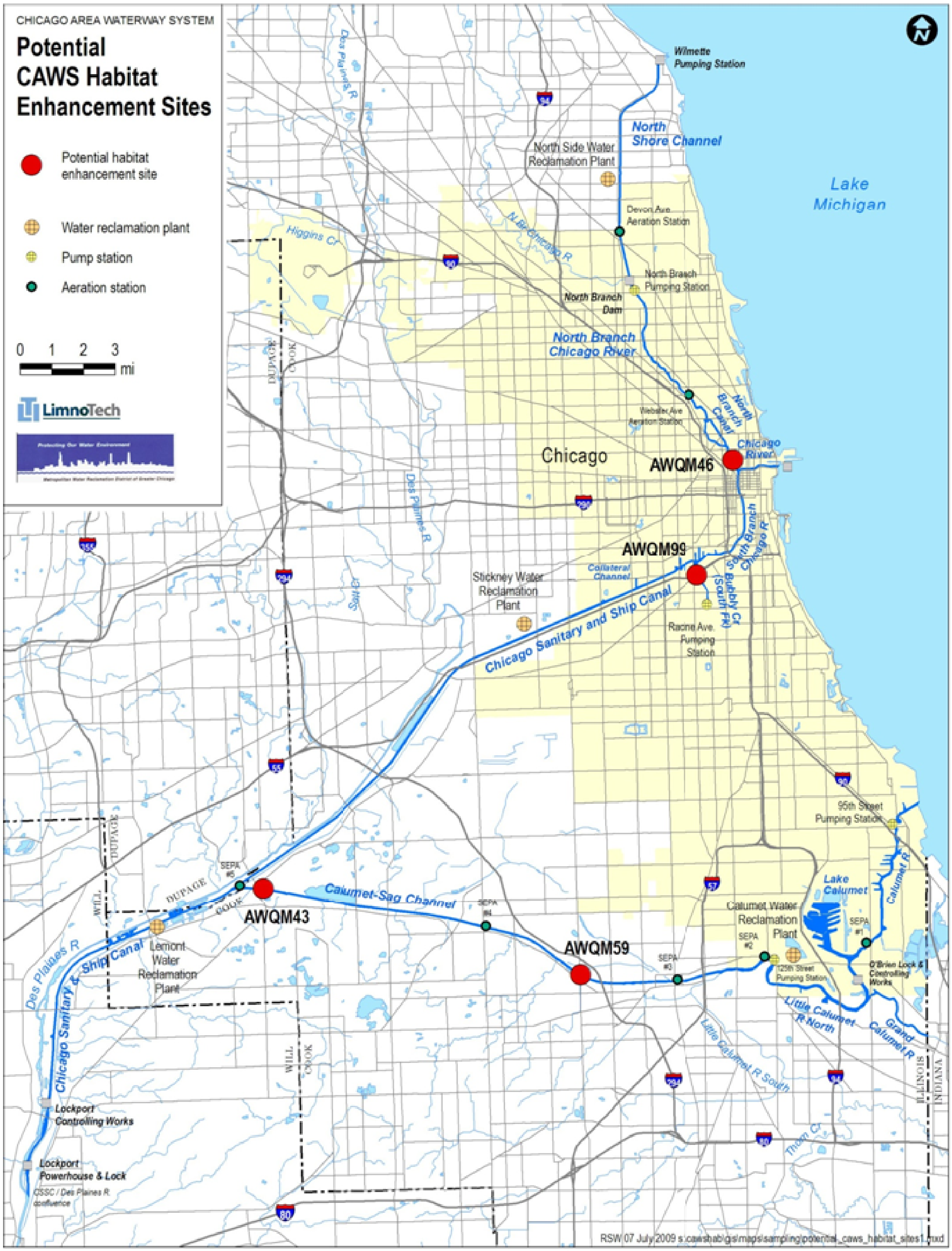

Figure 3-3: Locations of Habitat Restoration Conceptual Design Sites

Planning-level cost estimates were also prepared for the conceptual designs by Bioengineering. These estimates yielded unit costs, summarized in Table 3-4.

Table 3-4: Planning-Level Unit Costs for Habitat Improvement Techniques

Habitat Improvement Technique	Planning Level Unit Cost Estimate
Vegetated Revetment	$58/s.f.
Chamber Revetment	$94/s.f.
Sunken Structure	$122.50/s.f.
Floating Vegetation	$150/s.f.
Artificial Seaweed	$31/s.f.
Linear Shallows	$119/c.y.

More detailed cost breakdowns are provided in Appendix D. Some of these unit costs were translated into alternate unit costs (Table 3-5), to allow for estimation of total potential habitat improvement cost later in this report.

Table 3-5: Modified Planning-Level Unit Costs for Habitat Improvement Techniques

Habitat Improvement Technique	Planning Level Unit Cost Estimate
Vegetated Revetment[3]	$1,160/l.f.
Chamber Revetment[4]	$1,880/l.f.
Linear Shallows[5]	$53,000/ea.

Because they do not directly address primary habitat impairments, modified unit costs for the other techniques described were not prepared.

[3] Estimate assumes 20 vertical feet of bank face – 5 feet above water line and 15 feet below.
[4] Estimate assumes 20 vertical feet of bank face – 5 feet above water line and 15 feet below.
[5] Estimate assumes that linear shallow is approximately 12’ wide, 10’ deep, and 100’ long.

3.4.3 Improvement of Bank Pocket Areas

None of the conceptual habitat improvement design described above will directly address the bank pocket area attribute. It was assumed that this impairment can be addressed by excavation of small areas (approximately in the shoreline, stabilizing the banks using bioengineering techniques and the revegetating the riparian area near them. The estimated unit cost for this technique is summarized in Table 3-6.

Table 3-6: Conceptual Unit Cost Estimate for Creating Bank Pocket Areas

Project Element	
Mobilization/ Demobilization	$500
Earthwork[6]	$222
Bioengineered Bank Stabilization	$700
Riparian Vegetation	$1,120
Design/Oversight/ Contingencies	$500
Total	**$3,042/ea.**

It should be noted that these cost will vary significantly depending on a range of factors including the location, existing bank condition and materials, and the total number of bank pocket areas to be constructed. This estimate should suffice, however, for feasibility-level planning.

[6] Cost estimates assume that bank pocket dimensions will be 20’ long, 3’ wide and 2’ deep.

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4. CAWS HABITAT IMPROVEMENT POTENTIAL

One of the major objectives of the habitat improvement part of this Study was to determine, to the extent possible, what the habitat improvement potential of the various CAWS reaches is. In pursuing this objective, there are two questions that must be addressed:

1. Can the physical conditions in the reach be altered to improve habitat for fish? This question relates to the potential for physical conditions, determined by this Study to be most significantly related to fisheries condition, to be altered in a way that should benefit fish in keeping with the findings of the Study (i.e. enhancement/augmentation of positive conditions or reduction of negative factors).

2. If the physical conditions can be altered in a way that should benefit fish, is there an expectation that fisheries will be improved in the reach? In other words, if modifications to physical habitat are implemented, what will be the expected outcome with respect to fisheries quality?

These questions are addressed in this section, for each of the CAWS reaches evaluated in this Study.

It should be noted that the discussion below is focused on the physical habitat attributes that were identified as most statistically significant to fish in the CAWS in this Study. Because this Study focused on attributes that were identified for the entire system as a whole or for major groupings of reaches, habitat impairments categorized in Section 2 as "secondary" or other factors that may be significant in individual reaches are not accounted for. As an example of the latter, sudden, very high CSO discharges in Bubbly Creek may severely limit habitat potential there, but this local condition was not captured in the system-wide analysis. With respect to the "secondary" habitat impairments noted in Section 2, it is not possible to quantify the potential benefit of improving those attributes because they were not included in the habitat index. It should also be noted that, because the Study relied on the statistical comparison of habitat data with fish data using multiple linear regression to identify the habitat variables most significantly related to fisheries condition, habitat attributes that do not exhibit significant variation were not identified. This does not mean that a ubiquitous negative condition (e.g. lack of floodplain connectivity) is not bad for fish. As a result, some negative attributes were not accounted for in index, so the index likely represents an underestimate of habitat impairment. If these attributes were somehow included in the index, the habitat index scores would likely be lower.

4.1 ASSUMPTIONS FOR ASSESSMENT OF HABITAT IMPROVEMENT

Without the benefit of actually testing the benefit of potential habitat improvement measures, the assessment of habitat improvement potential must include some professional judgment. The rationale for determining whether a particular attribute can be altered requires a qualitative assessment. As such, the following assumptions were applied in assessing habitat improvement potential of the CAWS reaches:

- Because the CAWS habitat index was developed with the upper end reflecting the best existing conditions in the CAWS, it was assumed that a given habitat attribute in a given reach can only be improved to best condition that currently exists elsewhere in the CAWS.

- Certain habitat impairments were deemed to be not improvable in the CAWS, including maximum channel depth, manmade structures, lack of large substrate, and presence of organic sludge, as described in Section 2 of this report.

- Some potential habitat improvement measures may be infeasible, but for purposes of identifying improvement potential, it was assumed that they might be implemented. 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.

- In evaluating habitat attributes that can potentially be altered in a reach, the existing index scores for each attribute in the reach were reviewed. Some judgment was applied as to whether it is feasible to implement change in the habitat attribute to a degree sufficient to alter the index score for that attribute.

Each reach assessment is presented in the following section

4.2 REACH-SPECIFIC HABITAT IMPROVEMENT ASSESSMENT

The habitat improvement potential of each of the CAWS reaches is assessed in the following subsections, using the CAWS habitat index developed in this Study and presented in the Habitat Evaluation Report. This assessment involves only those primary habitat impairments that were identified as having some potential for improvement in Section 2 of this report:

- Lack of off-channel refuge

- Vertical wall banks

- Riprap banks

- Lack of macrophyte cover

- Limited overhanging vegetation
- Limited bank pocket areas

The focus on these primary habitat impairments deemed to have some potential for improvement is intended to allow quantification of the benefits of potential habitat improvements through recalculation of habitat index scores for each reach.

4.2.1 North Shore Channel

Study findings indicate that the North Shore Channel has the highest habitat quality for fish in the CAWS and that there is relatively little difference between the upper and lower portions of the channel, with respect to the primary physical habitat attributes identified in the Study. The primary physical habitat attributes for the CAWS, as identified in the habitat evaluation part of this Study, are assessed as follows:

- Lack of off-channel refuge – The North Shore Channel had a relatively low score for off-channel refuge, so this habitat attribute represents improvement potential in this reach. It is possible that construction of off-channel refuge could be accomplished to increase the score for this attribute in the North Shore Channel from 2 to 8 (the maximum score elsewhere in the CAWS).

- Vertical wall banks – The North Shore Channel currently has very little vertical wall banks, so this attribute cannot be significantly improved in this reach.

- Riprap-armored banks – The North Shore Channel has relatively little riprap (7% by bank length). Theoretically, riprap could be eliminated in the North Shore Channel (1.1 miles), which would slightly improve the index score for this attribute. It should be noted that, because riprap is placed to prevent bank erosion, it may be difficult to convince riparian land owners to replace riprap with bioengineering erosion control measures that might offer more naturalized banks and improved habitat quality.

- Lack of macrophyte cover – The North Shore Channel has the highest macrophyte cover in the CAWS and, therefore, represents the upper end of the habitat index range for this attribute. As such, this attribute cannot be improved in this reach.

- Overhanging vegetation – The North Shore Channel has the highest percentage of overhanging riparian vegetation (31%) in the CAWS. While there may be opportunities to improve overhanging vegetation on a local basis, there is no data to gage whether increases in this habitat attribute would have an effect on fisheries in the reach. Increasing the amount of overhanging vegetation would not increase the reach’s index score.

- Bank pocket areas[7] – The number of bank "pocket areas" could potentially be improved in the North Shore Channel. If bank pocket areas were increased to raise the reach score to 20, representing the highest score anywhere in the CAWS for this attribute, it would increase the index score for this reach.

Based on this review of primary physical habitat attributes in the reach, it appears that the only habitat attributes that could feasibly be altered and that would result in a change in the habitat index for the reach are off-channel refuge, riprap and bank pocket areas. Alteration of these attributes in the Upper North Shore Channel could increase the habitat index score from 75 to 80 (7% increase). In the Lower North Shore Channel, the index could potentially increase from 60 to 71 (18% increase). This change is still within the range of scores for the individual stations in the reach, suggesting that the changes would not likely have a significant impact on fisheries quality.

4.2.2 North Branch Chicago River

The findings of the Study indicate that, although the Upper and Lower reaches of the North Branch Chicago River[8] achieved similar habitat index scores, they differ with respect to some of the individual attributes. The primary physical habitat attributes in the North Branch Chicago River are assessed as follows:

- Lack of off-channel refuge – The North Branch Chicago River had a relatively low score for off-channel refuge (2 for the Upper reach and 5 for the Lower reach), so there is some potential to improve this habitat attribute. If additional off-channel refuge could be constructed, the scores for this attribute could theoretically be increased to 8 (the maximum score elsewhere in the CAWS).

- Vertical wall banks – Overall, slightly more than half of the banks in the North Branch Chicago River consist of vertical walls, with most of this in the Lower reach. Therefore, it is assumed that removal effort would focus on the Lower reach and it is further assumed that up to half of the vertical wall banks could be removed (about 4 miles) which would improve the index score for this attribute.

- Riprap-armored banks – Overall, the North Branch Chicago River has 33% riprap banks by length, the highest percentage of riprap in the CAWS, outside of the Cal-Sag Channel[9]. It may be possible to convert riprap bank protection to bioengineering erosion control measures which would reduce the percentage of riprap. Given limitations to this effort, it is reasonable to assume

[7] This represents the number of bank variations greater than 1 square meter that can serve as refuge from the main channel, per 400 m reach.
[8] The Upper North Branch Chicago River is defined as the portion north of Addison and the Lower North Branch Chicago River is the portion south of Addison.
[9] It should be noted that the upper North Branch Chicago River has a higher percentage (53%) of riprap than the lower North Branch Chicago River (18%).

that no more than half of the existing riprap (2.6 miles) could be improved, which would yield a change in index score.

- Lack of macrophyte cover – The North Branch Chicago River currently has a score of zero for macrophyte cover. If macrophyte cover can be improved in conjunction with removal of vertical wall banks, the habitat index score for this attribute could be increased. It is not possible to estimate what the increase in macrophyte cover might be, but since half of the reach would be affected by the removal of vertical wall banks, it is assumed that the new score could potentially be increased from zero to something in the mid-range of potential scores, approximately 5.

- Overhanging vegetation – Overhanging riparian vegetation varies from 25% in the Upper North Branch Chicago River to 5% in the Lower North Branch Chicago River. There may be opportunities to improve overhanging vegetation on a local basis. The Upper North Branch Chicago River already achieves a relatively high score for this attribute. However, overhanging riparian vegetation in the Lower North Branch Chicago River could be improved in conjunction with vertical bank wall removal. This would affect about half of the banks in the reach and it is assumed that this could double the index score for the Lower reach from 5 to 10.

- Bank pocket areas – The number of bank "pocket areas" is relatively high in the Upper North Branch Chicago River, but low in the Lower North Branch Chicago River. It is assumed that this attribute could be improved to increase the index score for the Upper reach from 15 to 17 and for the Lower reach by from 6 to 10.

Based on the review presented above, all six of the primary habitat attributes discussed could potentially be improved in the North Branch Chicago River. Implementing these improvements as described would increase the habitat index score for the Upper North Branch Chicago River from 49 to 58 (18% increase). Similarly, implementing these improvements in the Lower North Branch Chicago River would increase the habitat index score from 47 to 56 (19% increase).

4.2.3 Chicago River

The Chicago River exists in the midst of downtown Chicago and, therefore, has more severe limitations for habitat improvement than other reaches. For example, because of the developed urban nature of the riparian land of the Chicago River, it is assumed that any measure requiring significant use of that riparian land for habitat improvement would be infeasible. This has a significant impact on habitat improvement potential, as described below:

- Lack of off-channel refuge – The Chicago River actually scores quite high for this attribute, due to the high number of artificial areas of refuge in the reach.

As such, it is assumed that this attribute cannot be improved in the Chicago River.

- Vertical wall banks – Most of the banks in the Chicago River consist of vertical walls (97%), but removal would require significant use of existing riparian land which is infeasible in the Chicago River. Therefore, this attribute cannot be improved in this reach.

- Riprap-armored banks – The Chicago River has almost no riprap, so there is no significant potential to improve this habitat attribute.

- Lack of macrophyte cover – In this assessment, improvement of macrophyte cover is strictly limited to those areas where it can potentially be accomplished in conjunction with removal of vertical wall banks. If it is infeasible to remove vertical wall banks, there is no significant potential to improve macrophyte cover, so this attribute cannot be significantly improved in the Chicago River.

- Overhanging vegetation – The Chicago River has no overhanging riparian vegetation. Given the nature of the channel and riparian land uses, it is infeasible to implement a significant amount of overhanging vegetation in the reach.

- Bank pocket areas – There are no bank "pocket areas" in the Chicago River and given that nearly all of the banks consist of vertical walls, the opportunity to provide this attribute is nearly non-existent.

The discussion of the primary physical habitat attributes in the Chicago River presented above indicates that there is no feasible potential for significant habitat improvements to be implemented in the Chicago River.

4.2.4 South Branch Chicago River

The South Branch Chicago River received similar habitat index scores to the Chicago Sanitary and Ship Canal and the Cal-Sag Channel. The primary physical habitat attributes in the South Branch Chicago River are assessed as follows:

- Lack of off-channel refuge – The South Branch Chicago River had a relatively high score for off-channel refuge, so the potential for improvement of this attribute is limited. If additional off-channel refuge could be constructed, the score for this attribute in the South Branch would be increased to 8.

- Vertical wall banks – Most (90%) of the banks in the South Branch Chicago River consist of vertical walls. Assuming that up to half of the vertical wall banks could be removed (about 4 miles), the index score for this attribute would be improved.

- Riprap-armored banks – The South Branch Chicago River has relatively little riprap (4%), so even complete elimination of riprap would have relatively little effect on the habitat index score for this reach.

- Lack of macrophyte cover – The South Branch Chicago River currently has a score of zero for macrophyte cover. If macrophyte cover can be improved in conjunction with removal of vertical wall banks, the habitat index score for this attribute could be increased. It is not possible to estimate what the increase in macrophyte cover might be, but since half of the reach would be affected by the removal of vertical wall banks, it is assumed that the index score could potentially be increased from zero to something in the mid-range of potential scores, approximately 5.

- Overhanging vegetation – The South Branch Chicago River has nearly non-existent overhanging riparian vegetation and currently scores a zero in the habitat index for this attribute. It may be feasible to improve overhanging vegetation in conjunction with vertical bank wall removal. It is not possible to estimate what the maximum improvement potential is for this attribute in the South Branch, but for purposes of this assessment it is assumed that the index score would be improved from zero to 10.

- Bank pocket areas – The number of bank "pocket areas" in the South Branch Chicago River is relatively low (index score of 5), suggesting some room for improvement. However, the maximum increase in habitat index score that can be achieved is 4. Similar to the Lower North Branch Chicago River, it is assumed that this attribute score could theoretically be increased to 10.

The review above indicates some potential for improvement of these primary habitat attributes in the South Branch Chicago River. If the improvements described above were to be implemented, the habitat index score for the South Branch would be increased from 34 to 47 (38% increase).

4.2.5 Bubbly Creek

Bubbly Creek achieved a relatively low habitat index score, similar to the Cal-Sag Channel. It should be noted that, because fish are only sampled at one station in Bubbly Creek and only three fish sampling events were available from Bubbly Creek for use in the Study, the results of the overall habitat evaluation may not be completely representative of habitat limitations in Bubbly Creek. The primary physical habitat attributes in Bubbly Creek, based on the data collected in this Study, are described below:

- Lack of off-channel refuge – Bubbly Creek had a relatively low score for off-channel refuge (1), so there is some improvement potential for this attribute. The maximum possible index score for off-channel refuge is 8, but it is noted that there is substantial development along the banks of Bubbly Creek, which might limit the improvement potential for this attribute. Therefore, a maximum improved score of 4 is assumed.

- Vertical wall banks – Bubbly Creek has a significant quantity (35%) of vertical wall banks. Existing development would likely limit the amount of riparian land that can be used for removal of vertical wall banks, but for purposes of this assessment it is assumed that up to half of the vertical wall banks could be removed (about 0.5 miles), which would improve the index score for this attribute somewhat.

- Riprap-armored banks – As with the South Branch Chicago River, Bubbly Creek has relatively little riprap (3%), so even complete elimination of riprap would have relatively effect on the habitat index score for this reach.

- Lack of macrophyte cover – No significant macrophyte cover has been noted in Bubbly Creek and it was given an index score of zero for this attribute. If macrophyte cover can be improved in conjunction with removal of vertical wall banks, the habitat index score for this attribute could be increased. It is not possible to estimate what the increase in macrophyte cover might be, but for this assessment it is assumed that the new score could potentially be increased from zero to something proportional to the change in vertical wall banks, approximately 3.

- Overhanging vegetation – Bubbly Creek scored an 8 for this attribute. Assuming that additional riparian vegetation is part of the removal vertical wall banks, it is assumed that this score could be doubled, to 16.

- Bank pocket areas – Bubbly Creek has reasonably good score for bank "pocket areas" (9). It may be feasible to improve this number and, for purposes of this assessment, it is assumed that an improved index score of 12 could be achieved.

If the habitat improvements noted above were implemented in Bubbly Creek, the habitat index score for that reach would increase from 37 to 48, about a 30% increase.

4.2.6 Chicago Sanitary and Ship Canal

The Chicago Sanitary and Ship Canal is the longest reach in the CAWS and scored among the lowest ratings using the habitat index developed in this Study (reach-wide average score = 34). The primary physical habitat attributes in the Chicago Sanitary and Ship Canal, as identified in the habitat evaluation part of this Study, are assessed as follows:

- Lack of off-channel refuge – The Chicago Sanitary and Ship Canal scored in the middle of the range for off-channel refuge (4). For purposes of this assessment, if additional off-channel refuge could be constructed, the score for this attribute would be increased to 8.

- Vertical wall banks – The Chicago Sanitary and Ship Canal has a relatively high percentage (59%) of vertical walls, but approximately 78% of these vertical wall banks are the result of excavating the canal into the limestone bedrock. It is unreasonable to think that the vertical wall condition could be altered in these reaches, therefore only 13% of the banks in the CSSC can theoretically be converted vertical to sloping. Assuming that up to half of these vertical banks could be removed (about 2 miles), this attribute would be slightly improved from 59% to 52.5%, which accounts for 0.3 point of the total change in index score.

- Riprap-armored banks – There is relatively little riprap (5%) in the Chicago Sanitary and Ship Canal, so even complete elimination of riprap would have relatively little effect on the habitat index score for this reach.

- Lack of macrophyte cover – Although the Chicago Sanitary and Ship Canal scored only 1% for macrophyte cover on a reach-wide basis, there are local areas with higher percentages. As in other reaches assessed here, if macrophyte cover can be improved in conjunction with removal of vertical wall banks, the habitat index score for this attribute could potentially be increased proportionately. As with other reaches, it is not possible to estimate what the increase in macrophyte cover might be, but since the removal of vertical walls would affect about 30% of this reach, it is assumed that the index score for macrophyte cover would be improved to about the 30^{th} percentile of the index range for this attribute, approximately 3.

- Overhanging vegetation – The Chicago Sanitary and Ship Canal has relatively little overhanging riparian vegetation (5%). The same approach is taken for this attribute as for macrophyte cover, assuming that the overhanging vegetation can be improved to about the 30^{th} percentile of the index range for this attribute, for an improved score of 10.

- Bank pocket areas – The Chicago Sanitary and Ship Canal already scores relatively high for bank pocket areas (12). Assuming this attribute can be improved to the maximum amount, the index score would increase to 17.

Based on this review of primary physical habitat attributes in the Chicago Sanitary and Ship Canal, implementation of the habitat improvements noted above would increase the habitat index score for the reach from 34 to 43 (26% increase). This change is still within the range of scores for the individual stations in the reach, suggesting that the changes would not likely have a significant impact on fisheries quality.

4.2.7 Cal-Sag Channel

The Cal-Sag Channel scored among the lowest ratings in the CAWS using the habitat index developed in this Study (reach-wide average score = 37). The primary physical habitat attributes in the Cal-Sag Channel, as identified in the habitat evaluation part of this Study, are assessed as follows:

- Lack of off-channel refuge – The Cal-Sag Channel scored at the low end of the range for off-channel refuge (2). For purposes of this assessment, if additional off-channel refuge could be constructed, the score for this attribute could potentially be increased to 8.

- Vertical wall banks – The Cal-Sag Channel has a somewhat lower percentage (19%) of vertical walls, but approximately 20% of these vertical wall banks are the result of excavating the channel into the limestone bedrock. It is unreasonable to think that the vertical wall condition could be altered in these reaches, therefore only 15% of the banks in the CSSC can theoretically be converted vertical to sloping. Assuming that up to half of the vertical wall banks could be removed (about 1.2 miles), the index score for this attribute would be slightly improved.

- Riprap-armored banks – The Cal-Sag Channel has a relatively high percentage of riprap banks (53%), about the same percentage as the Upper North Branch Chicago River. It may be feasible to reduce this quantity, but given the limitations of such an effort, it was assumed that no more than half of the riprap in the Cal-Sag could feasibly be removed, reducing the percentage to 26.5, which accounts for 1.8 points of the total change in index score for this reach.

- Lack of macrophyte cover – The Cal-Sag Channel scored a zero for macrophyte cover on a reach-wide basis, although there may be local areas with macrophyte cover. As in other reaches assessed here, if macrophyte cover can be improved in conjunction with removal of vertical wall banks, the habitat index score for this attribute could potentially be increased proportionately. Given the limitations on estimating the increase in macrophyte cover, the consistent assumption was made the increase would be commensurate with the removal of vertical bank walls. Since the removal of vertical walls would affect about 10% of this reach, it is assumed that the index score for macrophyte cover would be improved to about the 10^{th} percentile of the index range for this attribute, approximately 1.

- Overhanging vegetation – The Cal-Sag Channel has the same overhanging vegetation percentage as the Chicago Sanitary and Ship Canal (5%). As with the Chicago Sanitary and Ship Canal, it is assumed that the overhanging vegetation can be improved to about the 30^{th} percentile of the index range for this attribute, for an improved score of 10.

- Bank pocket areas – As with the Chicago Sanitary and Ship Canal, the index score for bank “pocket areas” is relatively high in the Cal-Sag Channel (12). Improving this value to the maximum of 17 would increase the habitat index score somewhat.

Based on this review of primary physical habitat attributes in the Cal-Sag Channel, improvements to the primary habitat attributes that could feasibly be altered would increase the habitat index score from 37 to 44 (19% increase). This change is still within the range of scores for the individual stations in the reach, suggesting that the changes would not likely have a significant impact on fisheries quality.

4.2.8 Little Calumet River

The Little Calumet River received a habitat index score of 52, which was third only to the upper and lower North Shore Channel. The primary physical habitat attributes in the Little Calumet River are assessed as follows:

- Lack of off-channel refuge – The Little Calumet River had a relatively high score for off-channel refuge (6). For purposes of this assessment, if additional off-channel refuge could be constructed, the score for this attribute could potentially be increased to 8.

- Vertical wall banks – The Little Calumet River has the lowest percentage of vertical wall banks (5%) outside of the North Branch Chicago River. For purposes of this assessment, given the low quantity of this attribute, it was assumed that all vertical wall banks (0.6 mile) could be removed to reduce the index score to zero.

- Riprap-armored banks – The Little Calumet River has a percentage of riprap banks (17%), similar to the Lower reach of the North Branch Chicago River. It may be feasible to reduce this quantity, but given the limitations of such an effort, it was assumed that no more than half of the riprap in the Little Calumet River could feasibly be removed, reducing the percentage to 8.5, which accounts for 1.7 points of the total change in index score for this reach.

- Lack of macrophyte cover – The Little Calumet River scored low (1) for macrophyte cover on a reach-wide basis, although there may be local areas with higher percentages of macrophyte cover. As in other reaches assessed here, the consistent assumption was made that the increase would be commensurate with the removal of vertical bank walls. Since the removal of vertical walls would affect about 5% of this reach, it is assumed that the index score for macrophyte cover would be improved only slightly, to 2.

- Overhanging vegetation – The Little Calumet River scored 6% for overhanging vegetation. Assuming that increased riparian vegetation would occur in conjunction with removal of vertical wall banks and other projects, consistent with other reaches, it is assumed that it is feasible to increase overhanging vegetation to about the 30th percentile of the index range for this attribute, for an improved score of 10.

- Bank pocket areas – The Little Calumet River scored the highest for this attribute, so it was assumed that there is no potential for improvement.

Making the habitat improvements described above for the Little Calumet River would increase the habitat index score from 52 to 57 (about a 10% increase). This change is still within the range of scores for the individual stations in the reach, suggesting that the changes would not likely have a significant impact on fisheries quality.

4.3 POTENTIAL BENEFIT OF HABITAT IMPROVEMENT TO FISH

Each CAWS reach was evaluated with respect to the six key habitat variables identified in the CAWS Habitat Evaluation Report. Habitat variables that could potentially be improved were identified in each reach and the extent of feasible improvement was estimated based on conditions measured in system. The CAWS habitat index presented in the CAWS Habitat Evaluation Report was used to estimate what effect the habitat improvement would have on the habitat index score for each reach and a new potential habitat index score was calculated based on these estimates. The results of this are presented in Table 4-1.

Table 4-1: Potential for Habitat Improvement Using CAWS Habitat Index

Reach	CAWS Habitat Index Score	Potential Index Score After Habitat Improvement	Percent Change in Index Score
Upper North Shore Channel	75	80	7%
Lower North Shore Channel	60	71	18%
Upper North Branch Chicago River	49	58	18%
Lower North Branch Chicago River	47	56	19%
Chicago River	45	45	-
South Branch Chicago River	34	47	38%
Bubbly Creek	37	48	30%
Chicago Sanitary and Ship Canal	34	43	26%
Cal-Sag Channel	37	44	19%
Little Calumet River	52	57	10%

As indicated by the values in Table 4-1, the potential for habitat improvement varies widely from reach to reach. In the Chicago River, there is no potential for feasibly implementing significant habitat improvement. Outside of the Chicago River, the reaches that currently have the highest index scores have the lowest potential for habitat improvement on a percent basis and vice versa.

The information in the table above may be useful in prioritizing the CAWS reaches for habitat improvement, but it does not provide information about the potential benefits of the habitat improvements to the biological community. No clear and reliable way to define the potential biological benefit of habitat improvement was identified so, as an alternative, the question was approached by evaluating whether the potential benefit to the biological community would be measurable.

Analysis of fish data from the CAWS, reported in the CAWS Habitat Evaluation Report, shows that fish data are extremely variable, with significantly different metrics being calculated from fish data collected at the same stations during different sampling events. If it is assumed that the potential change in biological community will be reflected in the fish data, then the potential change must be larger than the natural variability of the data in order for it to be measureable. If the potential change in fish metrics resulting from habitat improvement is less than the normal variability of the fish data, there is little potential for a measureable improvement in fisheries.

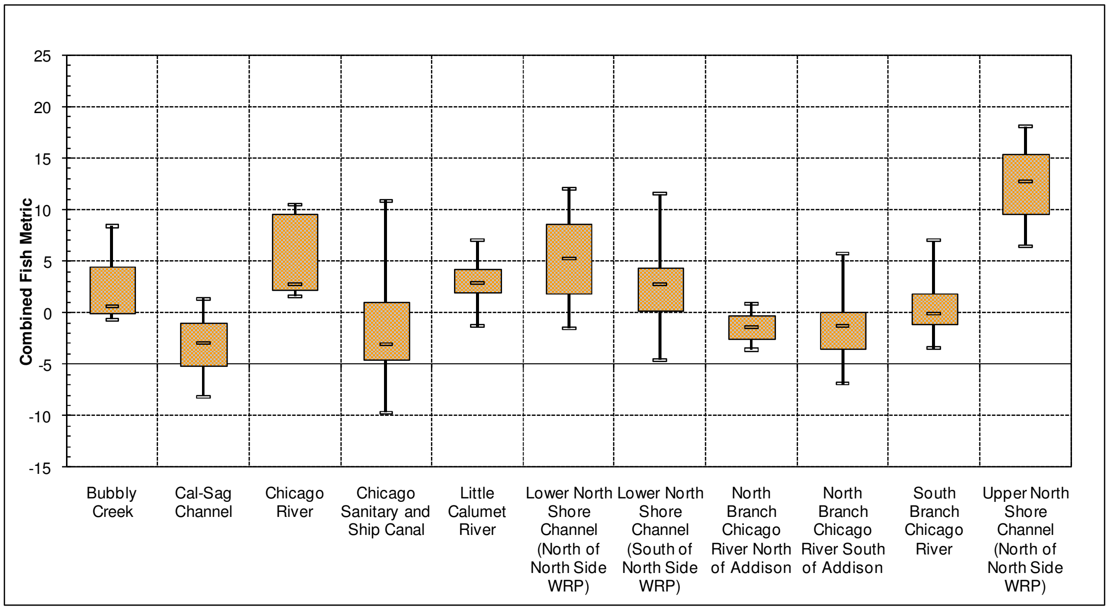

Figure 4-1: Variability in CAWS Fish Data by Reach as Indicated by the "Combined Fish Metric" (2001-2008)

The "whiskers" is Figure 4-1 represent the minimum and maximum values of the combined fish metric calculated in each reach and illustrate the full range of values for each reach. The coefficient of variation was calculated from these data and is expressed as a percentage in Table 4-2, along with the potential percent change in habitat index scores.

Comparison of the last two columns in Table 4-2 shows that the coefficient of variation of the fish data in each reach, expressed as a percentage, significantly exceeds the potential change in habitat index score in every reach. While the percent change in habitat index score is not a direct reflection of the potential change in the fish community, it is a reasonable approximation for comparison purposes. In most cases, the coefficient of variation is an order of magnitude greater than the percent change in habitat index score, suggesting that the natural variability of the fish data will overshadow any potential change in fisheries. Furthermore, the coefficients of variation in Table 4-2 represent the variability within a range of one standard deviation of the mean of the data and the actual data vary more widely than that.

Table 4-2: Potential Changes in "Combined Fish Metric" Resulting from Changes in CAWS Habitat Index

Reach	Percent Change in Index Score After Habitat Improvement	Coefficient of Variation of Fish Data as a Percentage
Upper North Shore Channel	7%	181%
Lower North Shore Channel	18%	170%
Upper North Branch Chicago River	18%	235%
Lower North Branch Chicago River	19%	238%
Chicago River	-	81%
South Branch Chicago River	38%	534%
Bubbly Creek	30%	175%
Chicago Sanitary and Ship Canal	26%	280%
Cal-Sag Channel	19%	87%
Little Calumet River	10%	79%

The preceding discussion supports the following findings:

- The habitat improvement potential of CAWS reaches, as measured by potential to feasibly improve significant habitat attributes in each reach, varies significantly across the CAWS, from zero in the Chicago River to 38% in the South Branch Chicago River.
- Some habitat attributes that were found to be statistically significant with respect to fish data are not feasibly alterable, such as maximum depth, the presence of manmade structures, large substrate, and presence of organic sludge.
- The reaches with the highest potential for habitat improvement, based on potential increases in habitat index scores, are the South Branch Chicago River and Bubbly Creek. However, even after the potential improvements, the resulting index scores indicate that habitat would remain relatively poor.
- Comparison of potential habitat index score changes and the natural variability of fish data in the CAWS, indicate that improvements in fisheries

that may potentially result from habitat improvement may be difficult to measure.

4.4 ESTIMATED COST OF HABITAT IMPROVEMENTS

One objective of this Study was to estimate the cost of potentially feasible habitat improvements in the CAWS. This was accomplished using the unit costs for conceptual habitat improvement techniques described in Section 3.4, in conjunction with estimated quantities for the primary improvements outlined in Section 4.2. The primary habitat impairments were assumed to be addressed by the conceptual habitat improvement designs as follows:

- Lack of off-channel refuge – The lack of off-channel refuge is assumed to be addressed by the construction of linear shallows, each approximately 12' wide and 200' long. Because the index score for this attribute was based on the number of refuges per 400 meter reach, the number of linear shallows required for the improvement in each CAWS reach was assumed equal to the increase in index score multiplied by the total reach length divided by 400 meters.

- Vertical wall banks – Vertical wall banks were assumed to be improved by removal as described in Section 3.4. The project cost was estimated as a direct calculation by linear foot of vertical wall bank to be removed, applying the unit cost for the 20' deep channel.

- Riprap-armored banks – It was assumed that riprap banks would be addressed by replacement with vegetated revetment.

- Lack of macrophyte cover – It was assumed that macrophyte cover would be addressed by removal of vertical wall banks.

- Overhanging vegetation – It was assumed that overhanging vegetation would be improved by removal of vertical wall banks.

- Bank pocket areas – It was assumed that this impairment would be addressed by the conceptual approach described in Section 3.4. Because the index score for this attribute was based on the number of bank pocket areas per 400 meter reach, the number of constructed bank pocket areas required for the improvement in each CAWS reach was assumed equal to the increase in index score multiplied by the total reach length divided by 400 meters.

Using the approach outlined here, the total cost per reach of the potential habitat improvements was calculated. This is presented in Appendix E and summarized in Table 4-3.

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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6. REFERENCES

Allan, J.D. 1995. *Stream Ecology: Structure and Function of Running Waters.* Dordrecht, The Netherlands: Kluwer Academic Publishers. 1995.

Boedeltje, G., Smolders, A. J. P., Roelefs, J. G. M., and van Groenendael, J. M. 2001. "Constructed Shallow Zones Along Navigation Canals: Vegetation Establishment and Change in Relation to Environmental Characteristics," *Aquatic Conservation: Marine and Freshwater Ecosystems*, Vol. 11, pp. 453-471.

Fischenich, J. Craig, 2003. *Effects of Riprap on Riverine and Riparian Ecosystems*. Washington, DC, U.S. Army Corps of Engineers.

Francis, R.A., Hoggart, S.P.G., Gurnell, A.M., and Coode, C., 2008. "Meeting the Challenges of Urban River Habitat Restoration: Developing a Methodology for the River Thames Through Central London Environmental Monitoring and Assessment Area"*, The Journal of the Royal Geographical Society*, Vol. 40, pp. 435-445.

Goulder, R., 2008. "Conservation of Aquatic Plants in Artifical Watercourses: Are Main Drains a Substitute for Vulnerable Navigation Canals?," *Aquatic Conservation: Marine and Freshwater Ecosystems*, Vol. 18, pp. 163-174.

Greenberg, J., 2002. *A Natural History of the Chicago Region*. The University of Chicago Press.

Hill, Libby. 2000. *The Chicago River: A Natural and Unnatural History*. Chicago: Lake Claremont Press. 2000.

Reyjol, Y., M.A. Rodriguez, N. Dubuc, P. Magnan, and R. Fortin, 2008. "Among- and Within-Tributary Responses of Riverine Fish Assemblages to Habitat Features". *Can. J. Fish. Aquat. Sci.* Vol. 65, No. 7, pp 1379-1392.

Sheehan, R. J., and Rasmussen, J. L., 1999. "Large Rivers," *Inland Fisheries Management in North America*. Christopher C.Kohler, and Wayne A.Hubert, eds., American Fisheries Society, Bethesda, Maryland.

Solzman, D.M. 2006. *The Chicago River: An Illustrated History and Guide to the River and its Waterways*, *2nd edition.* Chicago: University of Chicago Press.

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APPENDIX A:

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

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BIBLIOGRAPHY:

- Aarts, B.G.W. & Nienhuis, P.H. "Fish Zonations and Guilds as the Basis for Assessment of Ecological Integrity of Large Rivers. *Hydrobiologia* 500 (2003):157-178.

- Amisah, S., Cowx I.G. "Response of the Fish Populations of the River Don in South Yorkshire to Water Quality and Habitat Improvements" Environmental Pollution 108 (2000) : 191-199.

- Arlinghaus, R., Mehner, T., Cowx, I.G. "Reconciling Traditional Inland Fisheries Management and Sustainability in Industrialized Countries with Emphasis on Europe" Fish and Fisheries 3 (2002) : 261-316.

- Au, D.W.T., Pollino, C.A., Wu, R.S.S., Shin, S.T.F., Lau, S.T.F., Tang, J.Y.M. "Chronic Effects of Suspended Solids on Gill Structure, Osmoregulation, Growth, and Triiodothyronine in Juvenile Greeg Grouper Epinephelus coioides" Marine Ecology Progress Series 266 (2004): 255-264.
  - *Centre for Coastal Pollution and Conservation, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong SAR, China*

- Bash, J., Berman, C., "Effects of Turbidity and Suspended Solids on Salmonids" Washington State Transportation Center Research Project T1803, Task 42, November 2001.

- Bentrup, G. "Conservation Buffers: design guidelines for buffers, corridors, and greenways." Gen. Tech. Rep. SRS-109. Asheville, NC: Department of Agriculture, Forest Service, Southern Research Station. (2008) : 110.

- Bestmann, L. "Schwimmkampen" Wasser und Boden 32.4 (1980): 174-178.

- Bieberstein, A., Worsching, H., "Mastix-Stone Revetment for Overflow Sections of Dams and Levees" Institute of Soil Mechanics and Rock Mechanics, Germany, BAW-Workshop: Boden- und Sohl-Stabilität – Betrachtungen an der Schnittstelle zwischen Geotechnik und Wasserbau

- Boedeltje, G. A.J.P. Smolders, J.G.M. Roelofs and van Groenendael J.M. "Constructed Shallow Zones along Navigational Canals: Vegetation Establishment and Change in Relation to Environmental Characteristics." Aquatic Conservation: Marine and Freshwater Ecosystems 11 (2001): 453-471.

- Blue Wing Environmental, BioHaven Floating Island Brochure (2009).

- Caulk, A.D., J.E. Gannon, J.R. Shaw, and J.H. Hartig. (2000) *Best Management Practices*

- Collier, D., Cieniawski, S. "October 2000 and August 2002 Survey of Sediment Contamination in the Chicago River, Chicago Illinois" U.S. Environmental Protection Agency June 2003.

- Collares-Pereira, M.J., " The Role of Catchment Scale Environmental Management in Freshwater Fish Conservation" Fisheries Mangement and Ecology (2004) 11: 303-312, *Centro de Biologia Ambiental, Faculdade de Cieˆncias, Universidade de Lisboa, Lisboa, Portugal*

- Cowx, I.G. "Potential Impact of Groundwater Augmentation of River Flows on Fisheries: a Case Study from the River Ouse, Yorkshire, UK" Fisheries Management and Ecology, 7 (2000) : 85-96.

- Cowx, I.G., Gerdeaux, D. " The effects of Fisheries Management Practices on Freshwater Ecosystems" Fisheries Management and Ecology 11 (2004) : 145-151.

- Crump, Byron C., Koch, Evamaria W., "Attached Bacterial Population Shared by Four Species of Aquatic Angiosperms" Applied and Environmental Microbiology 74.19 (Oct 2008) : 5948-5957.

- *Soft Engineering of Shorelines.* Greater Detroit American Heritage River Initiative, Detroit, Michigan.

- Fager, Leon F., York, John C. "Floating Islands for Waterfowl in Arizona" Soil Conservation 41 (1975): 4-5

- Fish and Wildlife Service, Western Energy and Land Use Team. US Fish and Wildlife Service. Washington DC:
  - Edwards, E. A. and Twomey, K. A. "Habitat Suitability Index Models: Common Carp", July 1982
  - Williamson, K.L., Nelson, P.C. "Habitat Suitability Index Models: Gizzard Shad", September 1985
  - Stuber, R.J. Gebhart, G., Maughan, O.E. "Habitat Suitability Index Models: Large Mouth Bass", July 1982

- Fellow, C.S., Bunn, S.E., Sheldon, F., Beard, N.J. "Benthic Metabolism in Two Turbid Dryland Rivers" Freshwater Biology 54 (2009) : 236-253.

- Francis, R.A., Tibaldeschi, P., McDougall, L. "Fluvial Deposited Large Wood and Riparian Plan Diversity." Wetlands and Ecological Management 16. (2008) : 371-382.

- Francis, Robert A., Hoggart, Simon P.G. "Waste Not, Want Not: The Need to Utilize Existing Artificial Structures for Habitat Improvement Along Urban Rivers". Restoration Ecology 16(3) (2008): 373-381.

- Friberg, N., Kronvang, B., Hansen, H.O., Svendsen, L.M. "Long-term, Habitat-specific Response of a Macroinvertebrate Community to River Restoration" Aquatic Conservation: Marine and Freshwater Ecosystems 8 (1998) : 87-99.

- Garware Wall Ropes Ltd. Geosynthetics Division. Polymer Rope Gabion. Informational Brochure 2009.

- Goldsmith, W. "Lakeside Engineering" Land and Water, March April 1993, p. 6-9.

- Goldsmith, W., Bestmann, L."An Overview of Bioengieering for Shore Protection" International Erosion Control Association, Proceedings of Conference XXII, Reno Nevada, 1992 : 267-271.

- Goulder, R. "Conservation of Aquatic Plants in Artificial Watercourses: are main drains a substitute for vulnerable navigational canals?" Aquatic Conservation: Marine and Freshwater Ecosystems 18 (2007): 163-174.

- Hartwig, E., e.a, INUF des Verein Jordsand, Ahrensburg:UntersuchungenUber

- Hans Ole Hansen, (Editor), River Restoration: Danish Experience and Examples , Chapter 3 *Completed Watercourse Rehabilitation,* Ministry of Environment and Energy, National Environmental Research Institute, Silkeborg, Denmark.

- Hart, B., Cody, R. and Truong, P. "Hydroponic Vetiver Treatment of Post Septic Tank Effluent" Proceedings – The Third International Conference on Vetiver (ICV3), October 6–9, 2003, Guangzhou, P.R. China.

- Headley, T.R., Tanner, C.C. "Application of Floating Wetlands for Enhanced Stormwater Treatment: A Review" National Institute of Water and Atmospheric Research for Auckland Regional Council NWA project: ARC06231 (2006)

- Hoeger, Sven "Schwimmkampen-Germany's Artificial Floating Islands" Journal of Soil and Water Conservation 43.4 (1988) July-August.

- Houlahan, Jeff E., Findlay, C.Scott. "Estimating the 'Critical' Distance at Which Adjacent Land-use Degrades Wetland Water and Sediment Quality" Landscape Ecology 19 (2004): 677-690.

- Hull International Fisheries Institute:
  "Feasibility of Connecting Backwater and Floodplain Gravel Pits to the River Great Ouse" Environmental Agency (2004).

"Appraisal of the Impact of Fisheries Management on the Conservation Status of the Leven Canal, East Yorkshire" English Nature (1994, 1997, 1999, 2000, 2002)

- Illinois Environmental Protection Agency, "Artificial Structures for Fish Cover" , January 2004.

- Jahnig, S.C., Lorenz, A.W., Hering, D. "Restoration Effort, Habitat Mosaics, and Macroinvertebrates-does Channel Form Determine Community Composition?" Aquatic Conservation: Marine and Freshwater Ecosystems 19 (2009) : 157-169.

- Lake, R.G., Hinch, S.G. "Acute effects of Suspended Sediments Angularity on Juvenile Coho Salmon (Oncorhynchus kisutch)" Canadian Journal of Fisheries and Aquatic Sciences 56.5 (1999) : 862-867.

- Lutz, K.J. "Habitat Improvement for Trout Streams", Pennsylvania Fish and Boat Commission. Bellfonte, PA 40 (2007). Available online
- Mahoney, K. E. Paradise, Delorenzo, R., and DeRugoris, J. "CSO Sediment removal in an urban tributary".
- Mazej, Z., and Germ, M., "Trace Element Accumulation and Distribution in Four Aquatic Macrophytes" Chemosphere 74 (2009) : 642-647.

- Merritt, D.M. and Cooper, D.J. Riparian D.J. "Vegetation and Channel Change in Response to River Regulation: a comparative study of regulated and unregulated streams in the Green River Basin, USA" Regulated Rivers: Research and Management. 16 (2000) : 543-564.

- Mishra, V.K., Upadhyay, A.R., Pandey, S.K., Tripathi, B.D. "Concentrations of Heavy Metals and Aquatic Macrophytes of Govind Ballabh Pant Sagar an Anthropogenic Lake Affected by Coal Mining Effluent" Environmental Monitoring Assessment 141 (2008): 49-58.

- Nepf, H., Ghisalberti, M. "Flow and Transport in Channels with Submerged Vegetation" Acta Geophysica 56.3 (2008) : 753-777.

- Nunn, A.D., Harvey, J.P., Cowx I.G. " Benefits to 0+ Fishes of Connecting Man-made Waterbodies to the Lower River Trent, England River Research and Applications 23 (2007) : 361-376.

- Nunnally, Nelson R., Shields, Douglas F. JR., Hynson, James, "Environmental Considerations for Levees and Floodwalls" Environmental Management 11.2 (1987): 182-190.

- Patel, A. "Sustainable Waste-Water Management Policy. Supreme Court Committee for Class 1 Cities" 50 Kothner, Bagalur Road, Bangalore 56007. Water, Engineering Development Center; 2002 Loughborough University, Leicestershire, England.

- Pedersen, M.L., Friberg, N., Larsen, S.E. "Physical Habitat Structure in Danish Lowland Streams" River Research and Applications 20 (2004): 653-669.

- Pollux, B.J.A., Kososi, A., Verbeck, W.C.E.P. , Pollux , P.M.J. & van der Velde, G. "Reproduction, Growth and Migration of Fishes in a Regulated Lowland Tributary: Potential Recruitment to the River Meuse" Hydrobiologia (2006) 565:105-120.

- Rahman, Azizur,M., Hasegawa, H., Ueda, K., Maki, T., Rahman, M. Mahfuzur, (2008). "Arsenic Uptake by Aquatic Macrophyte *Spirodela polyrhiza* L: Interactions with Phosphate and Iron" Journal of Hazardous Materials 160 (2008): 356-361.

- Ruiz-Rueda, O., Hallin, S., Baneras,L. "Structure and Function of Denitrifying and Nitrifying Bacterial COmmunites in Relation to the Plant Species in a Constructed Wetland" Federation of European Microbiological Societies (FEMS) Microbial Ecology 67 (2009) 308-319.

- Riley, A., Restoring Streams in Cities, Island Press, 1998 p 354-393.

- Sand-Jensen, K., Friberg, N., Murphy, J (Editors), Running Waters: Historical Development and Restoration of Lowland Danish Streams, National Environmental Research Institute, Denmark (2006).

- Schwartz, J.S., Herricks, E.E. "Evaluation of Rock-Riffle Naturalization Structures on Habitat Complexity and the Fish Community in an Urban Illinois Stream" River Research and Applications, Wiley Interscience 23 (2007):451-466.

- Schwartz, J.S., Herricks, E.E. "Fish use of Ecohydraulic-based Mesohabitat Units in a Low-gradient Illinois Stream: implications for stream restoration" Aquatic Conservation: Marine and Freshwater Ecosystems 18 (2008) :852-866.

- Seabed Scour Control Systems Limited (SSCS), Artificial Seaweed Brochure, (2009).

- Seidel, Kathe, Happel, Helga, "Teiche und Pflanzen in der Abwassereinigung Teil 2" Wasserkalendar 20 (1986): 123-147.

- Shukla, O.P., Rai, U.N., Dubey, Smita "Involvement and Interation of Microbial Communities in the Transformation and Stabilization of Chromium during the Composting of Tannery Effluent Treated Biomass of *Vallisneria spiralis* L." Bioresource Technology 100 (2009): 2198-2203.

- Sigler, J.W., Bjornn, T.C., Everest, F.H. "Effects of Chronic Turbidity on Density and Growth of Steelhead and Coho Salmon" Transactions of the American Fisheries Society 113 (1984) : 113-142.

- Smith, JMB , Bayliss-Smith, T.P. "Kelp-Plucking: Coastal Erosion Facilitated by Bull-kelp *Durvillaea antartica* at Subarctic Macquarie Island" Antarctic Science 10.4 (1998) : 431-438.

- Steen, P.J. "Michigan Stream Fish: Distribution Models, Future Predictions, and Urban Impacts" Doctoral Dissertation, Natural Resources and Environment in the University of Michigan, (2008) 243pp.

- Stewart, Frank (P.I) "Biomimetic Floating Islands that Maximize Plant and Microbial Synergistic Relationships to Revitalize Degraded Fisheries, Wildlife Habitat, and Human Water Resources" 2007 Final Report to Montana Board of Research and Commercialization Technology, Floating Island International (2007).

- Stuber, R. J. Gebhart, G. and Maughan, O.E. 1982. Habitat Suitability Index Models: Largemouth Bass. Western Energy and Land Use Team. Washington, DC. 33pp.

- Vannote, R.L., Minshall, G.W. Cummins, K.W. , Sedell, J.R., Cushing, C.E. "The River Continuum Concept" Canadian Journal: Fisheries and Aquatic Science 37 (1980):130-137.

- Van Zyll DeJong, M.C., Cowx, I.G., Scruton, D.A. " An Evaluation of Instream Habitat Restoration Techniques on Salmonid Populations in a Newfoundland Stream" Regulated Rivers Research and Management 13 (1997) : 603-614.

- Weyand, M., Schittheim D. 2006. "Good Ecological Status in a Heavily Urbanized River: is it feasible?" Water, Science and Technology. Vol. 53:10, (2006) : 247-253.

- Will, Gary C., Crawford, Gurney I. "Elevated and Floating Nest Structures for Canada Geese" Journal of Wildlife Management 34 .3 (1970): 583-586.

- Williamson, K.L. and P.C. Nelson. 1985. Habitat suitability index models and in-stream flow suitability curves: Gizzard Shad. Western Energy and Land Use Team, US Fish and Wildlife Service, Washington, DC. 33pp.

- Yang, H., Shen, Z., Zhu, S., Wang, W. "Vertical and Temporal Distribution of Nitrogen and Phosphorus and Relationship with Their Influencing Factors in Aquatic-terrestrial Ecotone: a case study in Taihu Lake, China" Journal of Environmental Sciences 19 (2007): 689-695.

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APPENDIX B:

HABITAT IMPROVEMENT TECHNIQUE FACT SHEETS

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APPENDIX C:

HABITAT IMPROVEMENT CONCEPTUAL DESIGNS

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APPENDIX D:

HABITAT IMPROVEMENT PLANNING LEVEL COST ESTIMATES

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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 119	$/cy		$105,325		$53,620	
Floating Vegetation	Total Cost @ site 150	$/sf	$83,095		$62,594		
Artificial Seaweed	Total Cost @ site 31	$/sf		$101,999	$101,999	$101,999	
Chamber Revetment	Total Cost @ site 94	$/sf		$37,494	$18,747		
Vegetated Chamber Revetment	Total Cost @ site 58	$/sf			$23,248		
Sunken Structure	Total Cost @ site 122.5	$/sf	$29,391			$29,193	
Stormwater Wetland	Total Cost @ site 51	$/cy				$109,036	
Solar Aeration	Total Cost @ site 40480	ea			$40,480		
	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."

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

Item Description	Unit Price	Regionally Adjusted Price	Unit	Sample Site 46 no.of units	Sample Site 46 Cost	Sample Site 43(road) no.of units	Sample Site 43(road) Cost	Sample Site 99 no.of units	Sample Site 99 Cost	Sample Site 59 (road) no.of units	Sample Site 59 (road) Cost
		12% adjustment for Ill. 101.2									
Linear Shallow											
Clear & Grub	10.5	11.6	sy			890	$10,358			445	$5,179
Excavation Bulk	9.9	10.0	cy			1920	$19,257			740	$7,422
Fine Grading	1.2	1.21	sy			2100	$2,550			1000	$1,214
Demo wall baffle inlet	10,000	10120	ea			1	$10,120			1	$10,120
Access Road -9" deep gravel	9.9	10.0	sy			650	$6,519			110	$1,103
Geotextile	1.2	4.3	lf			2700	$11,584			1500	$6,436
Gravel	25	25	ton			900	$22,567			445	$11,158
Foreman		98.7	$/hr			72	$7,106			64	$6,317
Unskilled Labor (3 workers)		73	$/hr			216	$15,763			64	$4,679
		Total Cost @ site					$105,825				$53,630
	Est. Unit Cost	119	$/sy								
Floating Vegetation											
Floating Island (single 8' equilateral preplanted triangle)	1,600	1619	ea	40	$64,768			8	$12,954		
Simple flex floating islands geotex/coir buoy pipes	15	25	sf					900	$22,770		
plants 2" plug	5	5	ea					900	$4,554		
Anchor/buoy system	300	304	group	5	$1,518			6	$1,822		
Commercial Diving Team (tender, foreman & diver)	480	486	day	2	$972			1	$486		
Flat bed Boat/Installation	5,000	5060	day	2	$10,120			3	$15,180		
Foreman		98.7	$/hr	18	$1,777			9	$888		
Unskilled Labor (3 workers)		73	$/hr	54	$3,941			54	$3,941		
		Total Cost @ site			$83,095				$62,594		
	Est. Unit Cost	150	$/sf								
Artificial Seaweed											
Artificial Seaweed Cement Mat 3 x 6 (m) 9.8 x 19.7 (ft)	2211	2238	ea			16.5	$36,919	16.5	$36,919	16.5	$36,919
Gravel	25	25	cf			1000	$25,075	1000	$25,075	1000	$25,075
Lighted Marker buoy system	allowance	1	section				$10,000		$10,000		$10,000
Crane Barge (10,000 pounds), Tugboat and driver (union)	12000	12144	day			2	$24,288	2	$24,288	2	$24,288
Foreman		98.7	$/hr			18	$1,777	18	$1,777	18	$1,777
Unskilled Labor (3 workers)		73	$/hr			54	$3,941	54	$3,941	54	$3,941
		Total Cost @ site					$101,999		$101,999		$101,999
	Est. Unit Cost	31	$/sf								
Chamber Revetment											
(Tensar/Triton) Chamber Revetments (Rock)	14	14	sf			400	$5,667	200	$2,834		
(Tensar/Triton) Anchors	45	46	ea			40	$1,822	20	$911		
Crane Barge (10,000 pounds), Tugboat and driver (union)	12000	12144	day			2	$24,288	1	$12,144		
Foreman		98.7	$/hr			18	$1,777	9	$888		
Unskilled Labor (3 workers)		73	$/hr			54	$3,941	27	$1,970		
		Total Cost @ site					$37,494		$18,747		
	Est. Unit Cost	94	$/sf								
Vegetated Revetment											
(Tensar/Triton) Chamber Revetment with prevegetated coir mattress*	16	16	sf					400	$6,423		
(Tensar/Triton) Anchors	45	46	ea					40	$1,822		
Crane Barge (10,000 pounds), Tugboat and driver (union)	12,000	12144	day					1	$12,144		
Foreman		98.7	$/hr					9	$888		
Unskilled Labor (3 workers)		73	$/hr					27	$1,970		
		Total Cost @ site							$23,248		
	Est. Unit Cost	58	$/sf								
Sunken Structure											
Box Culvert 4x3, max 8000 lbs per unit	150	152	lf	60	$9,108					50	$7,590
Rip Rap		6	cf	960	$5,280					1200	$6,600
Crane Barge (10,000 pounds), Tugboat and driver (union)	12,000	12144	day	1	$12,144					1	$12,144
Foreman		98.7	$/hr	9	$888					9	$888
Unskilled Labor (3 workers)		73	$/hr	27	$1,970					27	$1,970
		Total Cost @ site			$29,391						$29,193
	Est. Unit Cost	122.5	$/sf								
ANCILLARY TREATMENTS											
Stormwater Wetland											
Clear & Grub	11.5	12	sy							715	$8,321
Excavation Bulk	9.9	10.0	cy							2145	$21,514
Fine Grading	1.2	1.21	sy							22000	$26,717
Dewatering	5,500	5566	ls							1	$5,566
Geotextile	4	4.3	lf							710	$3,046
Strip & Stockpile Top Soil	16	18	cy							360	$6,412
Erosion control blanket	3.5	6	sy							1400	$4,959
planting: seed, herbaceous plugs, inflorescence	35	38.2	sy							413	$12,810
Erosion and Sediment control	5.3	5	lf							490	$2,479
Foreman		98.7	$/hr							54	$5,330
Unskilled Labor (3 workers)		73	$/hr							162	$11,822
		Total Cost @ site									$109,036
	Est. Unit Cost	51	$/cy								
Solar Aeration											
Solar Aeration unit installed and light (Solar Bee, Inc (N.D.)	40,000	40480	ea					1	$40,480		
Mob/ Demob /restore site		Mob/ Demob			$32,000		30,000		42,000		48,000
SITE TOTALS		SITE TOTALS			$144,485		$283,318		$292,068		$341,841

Assumptions:
Linear Shallow
fine grading @3:1 assumed 3 ft elevation above water level
#59 road will be 12 feet wide, 35 yards long
#43 road will be 12 feet wide, 216 yards long
Floating Vegetation
Assume 30' anchor line, easily anchored in bottom sediment
Artificial seaweed
Signage notification buoys-10' spacing & anchored to artificial seaweed cement pad
Camber Revetment
Assuming the walls will support the anchors
Vegetated Revetment
Assuming the walls will support the anchors
Sunken Structure
Assume the unconsolidated sediment depth is 4 ft, site 46
Assume the unconsolidated sediment depth is 6 ft, site 59
Stormwater Wetland
Assumed an average depth of 3 ft- will need hydrological study to be sized
Aeration
Additionally-two units are recommended

"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."

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APPENDIX E:

SUMMARY OF ESTIMATED COSTS FOR REACH-WIDE HABITAT IMPROVEMENT

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