CHICAGO AREA WATERWAY SYSTEM HABITAT EVALUATION AND IMPROVEMENT STUDY:

HABITAT EVALUATION REPORT

Prepared for:
The Metropolitan Water Reclamation District of Greater Chicago

January 4, 2010

LimnoTech
Water | Environment | Scientists | Engineers

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EXECUTIVE SUMMARY

This report documents 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 Study objectives addressed in this report are as follows:

- Determine physical habitat characteristics for all reaches of the CAWS, using applicable physical habitat metrics and data collected from the CAWS.
- Use a multi-metric habitat index to evaluate physical habitat conditions in the CAWS.
- Use physical habitat data and the above multi-metric index to assess the relative importance of physical habitat to fish in the CAWS.
- Determine, to the extent possible with the data and analysis developed in this Study, a system of classifying or categorizing reaches within the CAWS according to their physical habitat.

Detailed physical habitat data were collected and the entire CAWS Study area was characterized. A number of physical habitat impairments were identified and have been described in this report. The major conclusions drawn from the habitat evaluation and data analysis conducted in this study are:

- Aquatic habitat is inherently limited in the CAWS by the system's form and function. Habitat in the CAWS is significantly limited by the design of the CAWS, most of which is manmade. The manmade reaches of the CAWS were built to support wastewater effluent conveyance and commercial navigation. The reaches that were once natural streams have been heavily modified to serve these purposes and the changes are unlikely to be reversed as long as the CAWS needs to serve these functions. The form and uses of the CAWS impose severe limitations on physical habitat in the system.
- Physical habitat is more important to fish in the CAWS than dissolved oxygen. When key physical habitat variables and dissolved oxygen metrics are statistically compared to fish data collected between 2001 and 2008 in the CAWS, it is apparent that habitat is much more important to fish than dissolved oxygen. Multiple linear regression shows that the dominant habitat variables identified in this study had an r-squared of 0.48 with fish, indicating that these habitat variables explain as much as 48%, or about half, of the variability in the fish data.
- The ability of physical habitat to explain about half of the variability in fish data is excellent, considering the natural variability in the fish data itself. As

stated above, about half of the variability in fish data in the CAWS is explained by physical habitat, in particular certain key habitat variables identified in this study. Of the half of fish data variability not explained by the key habitat variables, most is explainable by natural variation in the fish data from one sampling event to another at each location. In other words, fish samples exhibit large temporal variability at any given location in the CAWS and when the portion of fish data variability not explained by habitat is statistically analyzed, it is most related to the variation at sampling locations over time, independent of habitat changes.

- Dissolved oxygen is relatively poor at explaining variability in fish data in the CAWS. Dissolved oxygen does not, for the most part, have a statistically significant relationship with fish in the CAWS. Various measures of dissolved oxygen were tested, including compliance with existing and proposed water quality standards, average and minimum DO, and percent of time below various DO concentration thresholds. The strongest relationship identified between any of these metrics and the combined fish metric had an r-squared value of 0.27, which is about half as good as the key habitat variables identified in this study. The other four DO measures tested had r-squared values ranging from 0.02 to 0.08. This indicates that physical habitat, not water quality, is the most limiting factor for fish in the CAWS today.

Six key habitat variables were identified through a process of sequentially reducing the habitat variables and ultimately through multiple linear regression with CAWS fish data. This process identified the following key physical habitat attributes as being critically important to fish in the CAWS:

- Maximum depth of channel
- Off-channel bays
- Percent of vertical wall banks in reach
- Percent of riprap banks in reach
- Manmade structures in reach
- Percent macrophyte cover in reach

Statistical analysis of habitat data with fish data from the CAWS showed that 48% of the variability of fish data collected from 2001 – 2007 can be explained by these key habitat variables. DO alone can only explain between 2% and 27% of the variability in the same fish data set.

The relative importance of physical habitat to fish in the CAWS was determined through statistical analysis of habitat, fish, and water quality data. Addition of a key water quality metric (percent of time dissolved oxygen is less than 5 mg/L) in the multiple linear regression with the key habitat variables only increased the explanatory power of the regression by only 4%.

A CAWS-specific habitat index was created using the six key habitat variables identified in this Study along with other important variables. The CAWS-specific habitat index was used to score individual sampling stations as well as the major reaches in the CAWS, in order to determine whether the findings of this Study can help classify the reaches according to the physical habitat variables that are most important to fish in the CAWS. When applied to fish data averages over the period of 2001 – 2008, the CAWS habitat index compared well ($r^2 = 0.48$), indicating that the index is good indicator of habitat suitability for fish in the CAWS.

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1. INTRODUCTION

This report documents a study of aquatic habitat in the Chicago Area Waterway System. The Chicago Area Waterway System Habitat Evaluation Study (the Study) was conducted by LimnoTech under contract to the Metropolitan Water Reclamation District of Greater Chicago (the District).

1.1 REPORT STRUCTURE

This report is structured to present the Study in a logical, explanatory manner and to facilitate its use by readers with a range of technical backgrounds. The major sections of the report are as follows:

- Section 1: Introduction – This section presents the Study objectives and an introduction to the CAWS.
- Section 2: Habitat Evaluation Approach – This section provides an overview of the approach used in this Study and the scientific rationale for that approach.
- Section 3: Data Summary – Section 3 describes the types, sources, and quantities of data used in this Study.
- Section 4: Description of Habitat Conditions in the CAWS – This section provides a summary description of the physical conditions in the CAWS that are relevant to physical habitat evaluation, based on observations and the data described in Section 3.
- Section 5: Description of Aquatic Biota in the CAWS – This Section summarizes existing aquatic life in the CAWS, based on the data used in this Study, focusing on fish and macroinvertebrates.
- Section 6: Habitat Data Analysis – Section 6 discusses the process used to identify key habitat variables in the CAWS, through a systematic review and reduction of potential variables. It also presents the analysis of fish and habitat data from the CAWS, to identify the most significant habitat variables to fisheries and to understand the relative importance of physical habitat, as compared to other factors such as water quality.
- Section 7: Development of a CAWS Habitat Index – Section 7 presents the development of a system-specific habitat index for the CAWS, based on the results of the analysis presented in Section 6.
- Section 8: CAWS Habitat Evaluation Summary – Section 8 presents a summary of the key findings of habitat evaluation conducted in this Study.

1.2 STUDY OBJECTIVES

This 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 key objectives of the habitat evaluation portion of the Study are as follows:

- Determine physical habitat characteristics for all reaches of the CAWS, using applicable physical habitat metrics and data collected from the CAWS.
- Use a multi-metric habitat index to evaluate physical habitat conditions in the CAWS.
- Use physical habitat data and the above multi-metric index to assess the relative importance of physical habitat to fish in the CAWS.
- Determine, to the extent possible with the data and analysis developed in this Study, a system of classifying or categorizing reaches within the CAWS according to their physical habitat.

1.3 CHICAGO AREA WATERWAY SYSTEM OVERVIEW

As the name implies, the Chicago Area Waterway System (CAWS) is a system of waterways in the vicinity of the Chicago metropolitan area (Figure 1-1), used primarily for conveyance of treated municipal wastewater, commercial navigation, and flood control. The overall length of the CAWS is approximately 78 miles, of which about 75 percent are manmade canals (District, 2008). The rest are formerly natural streams that have been dredged, straightened, widened, realigned, and otherwise modified to facilitate the uses listed above. The construction and modification history of the reaches of the CAWS are summarized in Table 1-1.

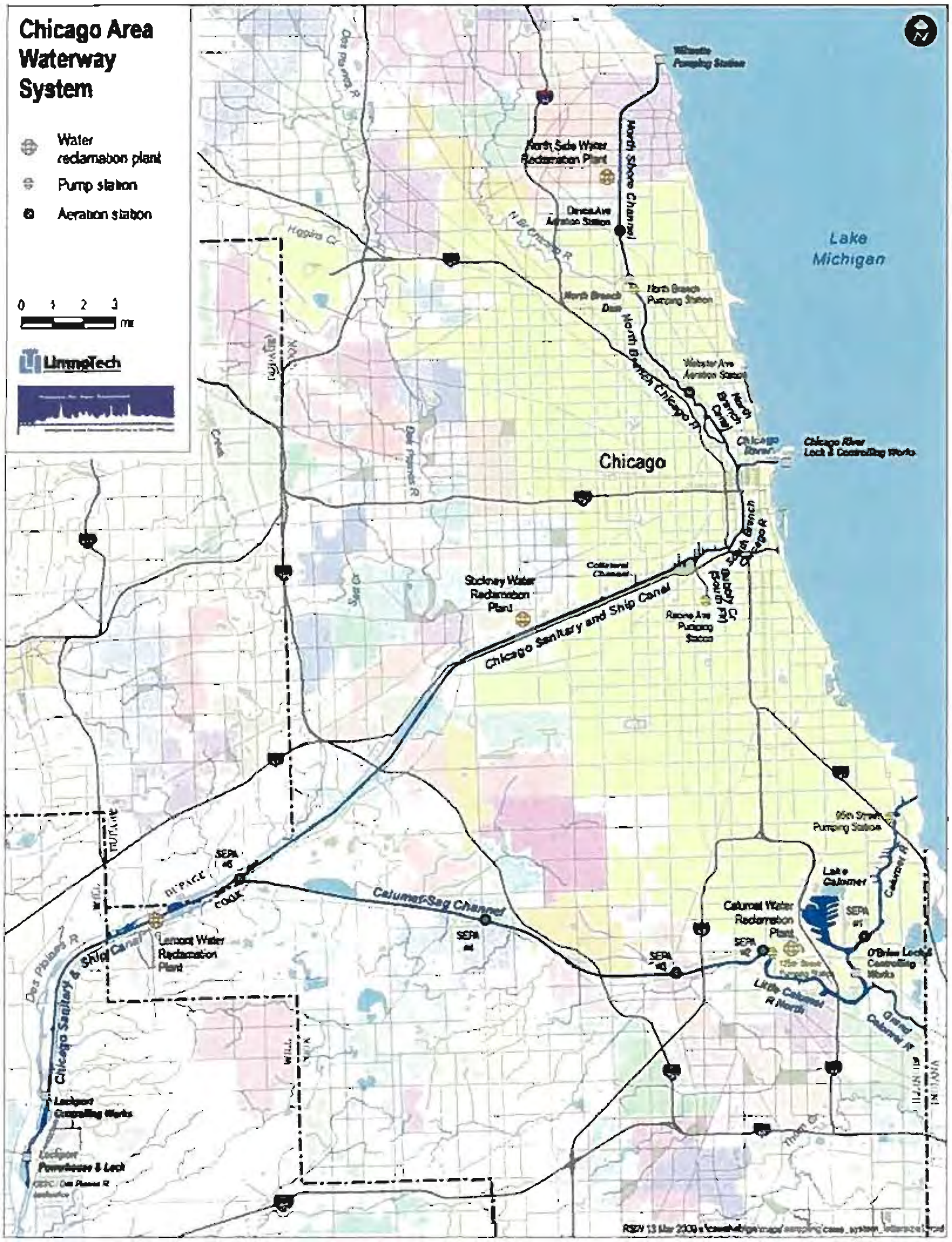

Figure 1-1: The Chicago Area Waterway System Habitat Evaluation and Improvement Study Area.

Table 1-1: Construction and Modification History of the CAWS (Greenberg, 2002; Hill, 2000; Ramey, 1953; 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

Just as the origin of natural rivers is important to understanding their physical habitat, it is equally important to understand the origin of the CAWS. As stated previously, most of the CAWS are excavated channels for conveyance of wastewater effluent and navigation, and these continue to be the primary purposes for which the CAWS are maintained today. The reaches that were originally natural streams or rivers have been so extensively altered that they bear little or no resemblance to their original condition. Brief summaries of each of the major reaches of the CAWS are provided below.

1.3.1 North Shore Channel

The northernmost segment of the CAWS is the North Shore Channel, which extends from Lake Michigan at Wilmette Harbor in Wilmette to the confluence with the North Branch Chicago River near Foster Avenue in Chicago and was constructed between 1907 and 1910 (see Figure 1-2). The North Shore Channel was designed to increase flow for dilution and flushing of wastewater in the North Branch Chicago River by connecting it to Lake Michigan. The Channel consists of relatively straight segments (see Figure 1-3) and is approximately 7.7 miles long, 90 feet wide, and 5 to 10 feet deep. Pumps at the Wilmette Pumping Station convey water from Lake

Michigan into the channel which flows south toward the North Branch Chicago River. This flow supplements flow from the North Branch Chicago River watershed, which is regulated by a dam at the confluence of the two waterways.

1.3.2 North Branch Chicago River

The lower 7.8 mile portion of the North Branch Chicago River lies within the CAWS (see Figure 1-1). Although the North Branch Chicago River was once a natural meandering river with consistent bank overflow, modifications to the channel to improve drainage began as early as the 1850s (Hill, 2000). Large scale straightening, widening, and deepening of the North Branch Chicago River was conducted between 1904 and 1907. The upper 5.1 miles of the North Branch (Figure 1-4), above Touhy Avenue, retains some bends, but has been significantly altered. Its width varies between 150 and 300 feet and it is 5 to 10 feet deep. The lower 2.6 miles (Figure 1-5) has been significantly straightened and channelized, with a width of approximately 90 feet and a depth of about 10 feet.

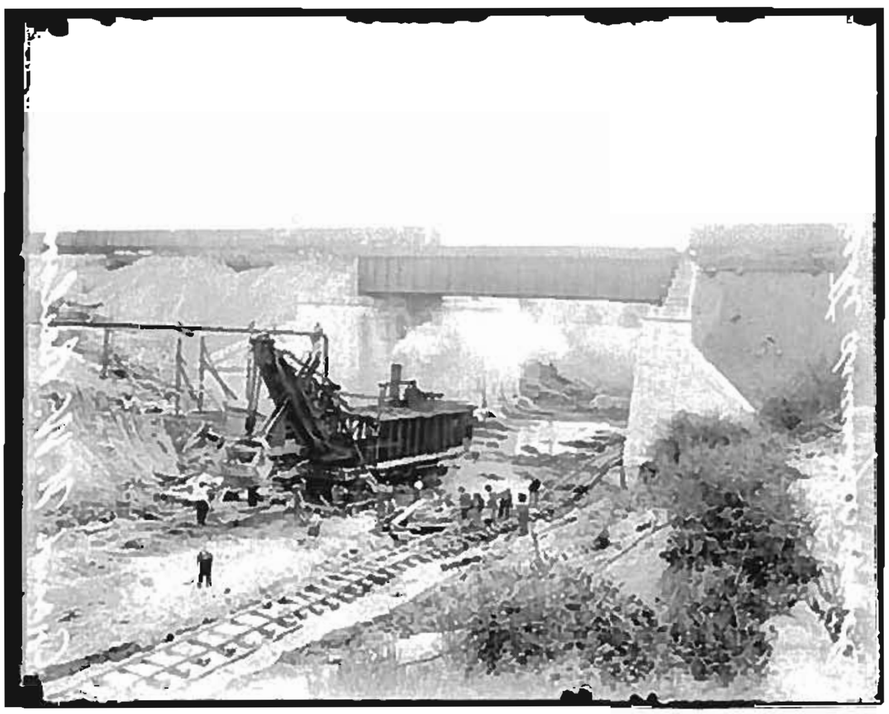

Figure 1-2: North Shore Channel Construction, 1910 (Chicago Daily News).

Figure 1-3: North Shore Channel, 2008.

Figure 1-4: Northern Segment of North Branch Chicago River, 2008.

Figure 1-5: Southern Segment of North Branch Chicago River, 2008.

1.3.3 North Branch Canal

In 1857, the 1.1-mile North Branch Canal was constructed to bypass a major bend in the North Branch Chicago River to reduce travel time up the river. The land isolated by the construction of the canal is now known as Goose Island. The North Branch Canal is 80 to 120 feet wide and 4 to 8 feet deep.

1.3.4 Chicago River

The 1.6-mile Chicago River extends from Lake Michigan west to the confluence of the North Branch Chicago River and the South Branch Chicago River (Figures 1-6 and 1-7). The mouth of the Chicago River was modified as early as 1816 (Hill, 2000) and river redesign continued through the 19th century as wastewater and drainage flows increased. Modifications included deepening, straightening, widening, and channelization. The Chicago River originally flowed into Lake Michigan, but with the completion of the Chicago Sanitary and Ship Canal in 1900 (see below), flow was reversed. The Chicago River Lock & Controlling Works began operating in 1939 to control the flow of Lake Michigan water into the Chicago River. The Chicago River is 200 to 400 feet wide with mostly vertical walled sides and is 20 to 26 feet deep.

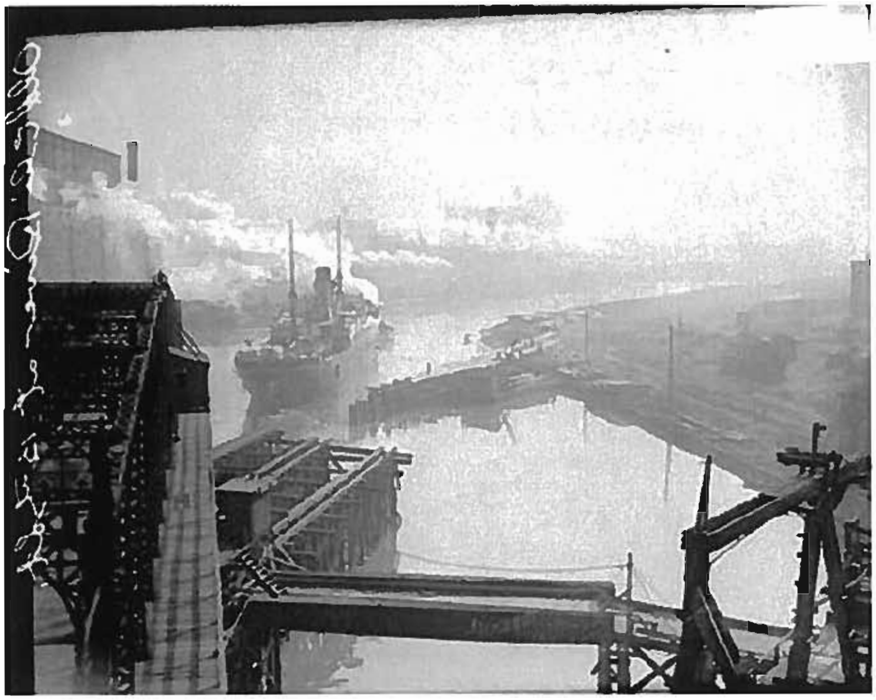

Figure 1-6: Chicago River, 1929.

Figure 1-7: The Chicago River, 2008.

1.3.5 South Branch Chicago River

The South Branch Chicago River (Figure 1-8) is approximately 4.6 miles long and flows west-southwest from the confluence of the Chicago River and the North Branch Chicago River. Although it generally follows its original course, major straightening and channelization of the South Branch to facilitate navigation occurred between 1928 and 1930. Like the Chicago River, the South Branch originally flowed toward Lake Michigan but its flow was reversed with the completion of the Chicago Sanitary and Ship Canal. The West Fork of the South Branch was completely filled in the 1920s and 1930s (Hill, 2000). The South Fork of the South Branch exists today and is described below. The South Branch is generally between 200 and 250 feet wide and its depth ranges from 15 to 20 feet.

Figure 1-8: The South Branch Chicago River, 2008.

1.3.6 South Fork of the South Branch Chicago River (Bubbly Creek)

The South Fork of the South Branch Chicago River (Figures 1-9 and 1-10) is a tributary to the South Branch and is approximately 1.5 miles long. The South Fork has been known as Bubbly Creek for more than a century because it received wastes from the Chicago stockyards starting in the second half of the 19th century and the decomposing organic waste on the bed of the creek created gases that bubbled to the surface. In 1866 the Union Stock Yards were located on the South Fork to centralize disposal of slaughterhouse wastes as a public health measure. Bubbles from gas production in the sediments are still visible today. Portions of Bubbly Creek have been straightened and channelized over time and the arms of Bubbly Creek were filled in the 1910s and 1920s. Bubbly Creek originally drained wetlands south of the City, but the only flows it receives today are urban storm water and occasional combined sewer overflow from the Racine Avenue Pumping Station. It is between 100 and 200 feet wide, with an average depth of 10 feet.

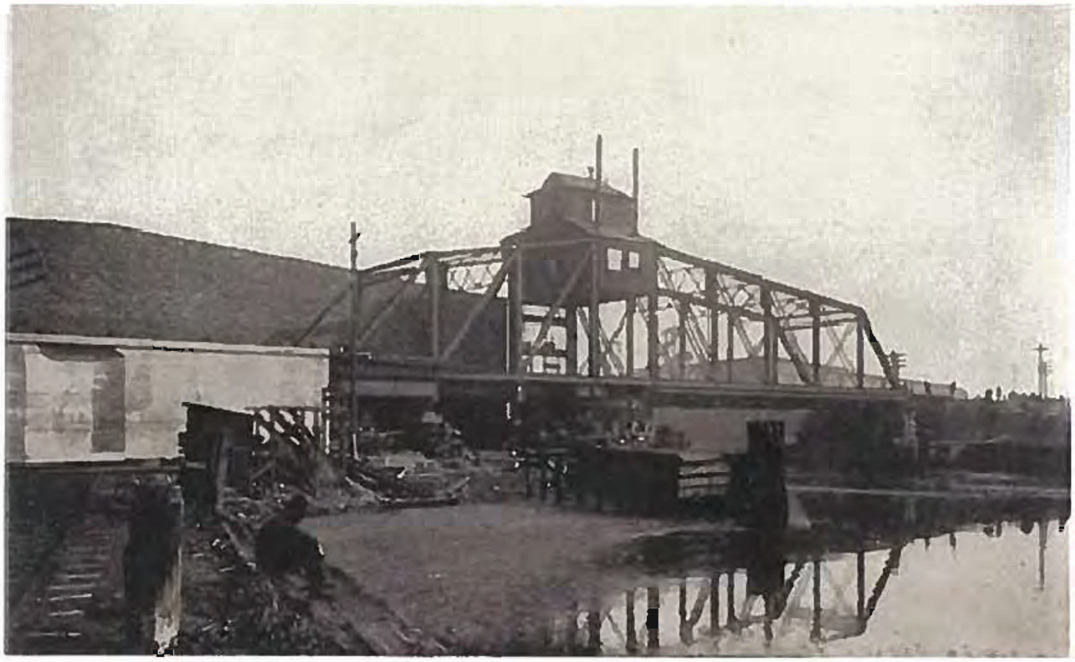

Figure 1-9: Bubbly Creek, 1902 (University of Illinois at Chicago).

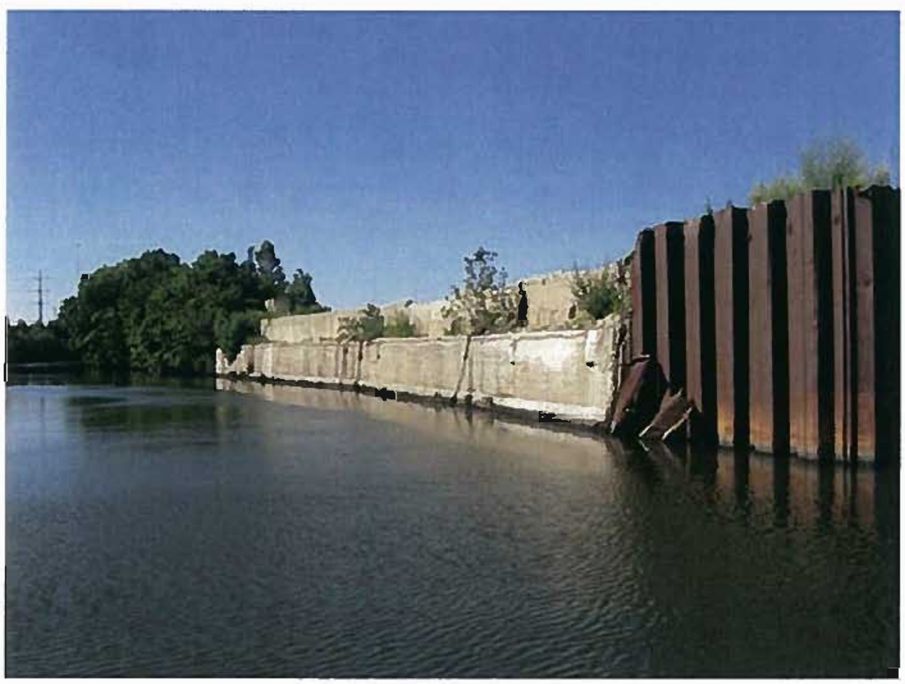

Figure 1-10: Bubbly Creek, 2008.

1.3.7 Chicago Sanitary and Ship Canal

The Chicago Sanitary and Ship Canal (CSSC) was constructed between 1892 and 1900 with the specific intention of reversing flow from the Chicago River system. Wastewater discharges and urban drainage from Chicago flowed into Lake Michigan prior to that time and had grown to threaten the City's drinking water intakes in the Lake. The 31.3 mile CSSC was constructed to drain the Chicago River system and the City's effluent westward, away from Lake Michigan to the Des Plains River. The CSSC completes a commercial navigational waterway connecting Lake Michigan to the Mississippi River. Near the southern terminus of the CSSC is the Lockport Powerhouse and Lock, just upstream of the confluence of the CSSC with the Des Plaines River. The CSSC is a generally straight canal with a few major bends. Its width varies between 160 and 300 feet and its depth varies between 20 and 27 feet over most of its length. Portions of the CSSC were excavated into bedrock (see Figures 1-11 and 1-12).

Figure 1-11: The Chicago Sanitary and Ship Canal under Construction, Santa Fe Railroad Bridge at Lemont, October 18, 1899

(Chicago Historical Society, The Electronic Encyclopedia of Chicago, 2005).

Figure 1-12: The Chicago Sanitary and Ship Canal in 2008.

1.3.8 Calumet-Sag Channel

The 16.1 mile Calumet-Sag (Cal-Sag) Channel (CSC) is a manmade canal constructed between 1911 and 1922 to reverse the flow of the Calumet River away from Lake Michigan, westward to the Des Plaines River (Figures 1-13 and 1-14). The CSC was excavated through limestone and bedrock (Hill, 2000). Upon completion, the CSC connected the Little Calumet River to the CSSC. It was widened in the 1960s to improve navigation. Today, the CSC is approximately 225 feet wide and 10 feet deep.

Figure 1-13: The Cal-Sag Channel under Construction, 1914
(Chicago Historical Society, The Electronic Encyclopedia of Chicago, 2005).

Figure 1-14: The Cal-Sag Channel in 2008.

1.3.9 Little Calumet River

Originally a reach of the Grand Calumet River, the 6.1 mile Little Calumet River (Figure 1-15) underwent major hydrologic modifications beginning in the 1870s. Flow from the Grand Calumet River was diverted into the widened, straightened, and deepened Little Calumet River. With the completion of the Calumet-Sag Channel and the Blue Island Controlling Works (operational from 1922 to 1965) the flow of the Little Calumet River was reversed to flow westward into the Calumet-Sag Channel. The Little Calumet River is between 250 and 350 feet wide and is approximately 12 feet deep.

Figure 1-15: The Little Calumet River in 2008.

The construction and modification of the CAWS is summarized in Figure 1-16.

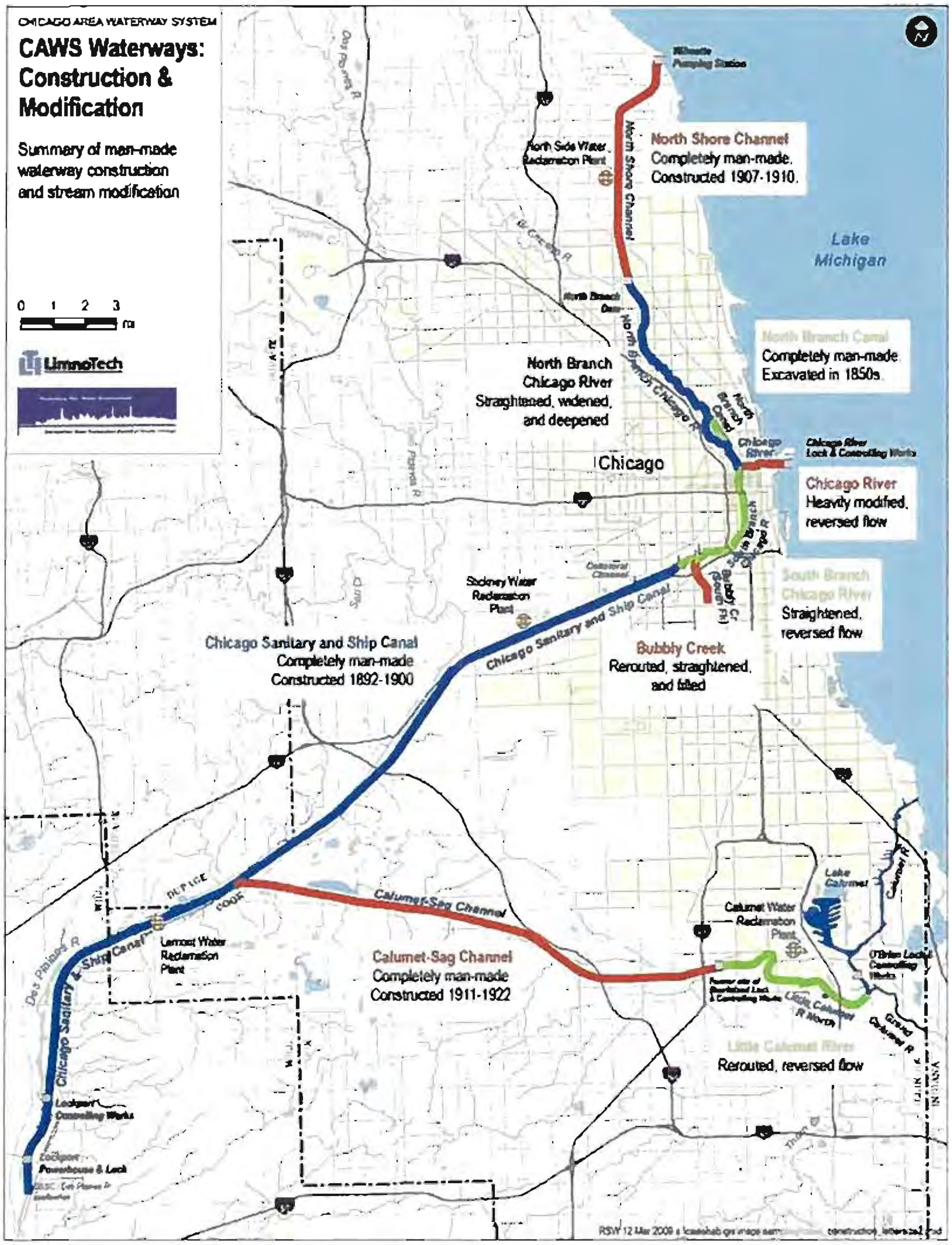

Figure 1-16: Construction and Modification History of the CAWS.

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2. HABITAT EVALUATION APPROACH

Because the objectives of this Study focused on understanding the importance of physical habitat to aquatic life in the CAWS and on identifying which particular habitat factors are relatively more important than others, it was logical to use bioassessment as the basis for the study. As stated in recent technical guidance published by the United States Environmental Protection Agency (USEPA):

> "The aquatic life of streams and rivers (fish, insects, plants, shellfish, amphibians, etc.) integrates the cumulative effects of multiple stressors generated by both point source and non-point source (NPS) pollution. Bioassessments, consisting of surveys and other direct measures of aquatic life, are the most effective way to measure the aggregate impact of these stressors of waterbodies. Bioassessments allow evaluation of the biological integrity of a waterbody…" (Flotemersch et al., 2006)

This approach was especially relevant in light of current proposals for modification of the water quality standards for the CAWS and the designated aquatic life uses that are part of those proposed standards. This section provides a brief background on the history, use, and applicability of bioassessments in ecological evaluation of surface waters and describes the general methodology used in this study.

2.1 BIOASSESSMENT OVERVIEW

Bioassessments are used by water quality management agencies in their establishment of water quality standards, assessment of designated use attainment, evaluation of the effectiveness of mitigation and restoration activities and as a contributor to the Total Maximum Daily Load (TMDL) process (Flotemersch et al., 2006). Bioassessments more accurately detect and identify water quality conditions and sources of impairment, however it appears that the designation of impairment through many regulatory programs do not necessarily identify the pollutant or stressor causing the impairment (D'Ambrosio et al., 2009).

Although surface water body regulation often focuses on water quality, there are other key factors that must be considered when evaluating the health of aquatic ecosystems. These key factors combine to form the biological integrity and ecological health of a system (Karr, 1995; Rankin, 1995; Karr and Yoder, 2004) and are at the interface of anthropogenic stressors and aquatic biota (Figure 2-1).

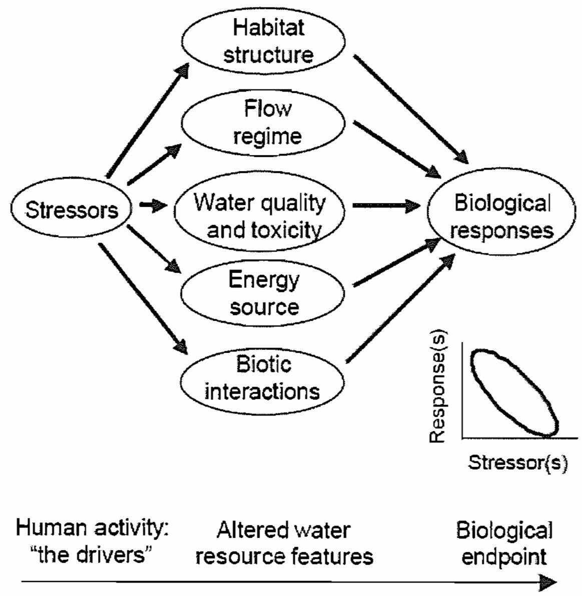

Figure 2-1: Key Factors Related to Health of Aquatic Systems (from Karr and Yoder, 2004).

Monitoring programs across the country are applying a range of approaches for assessing aquatic system conditions. Given the anthropogenic alterations imposed on most large rivers, programs could improve their assessment of biotic conditions by evaluating patterns of variation against anthropogenic stressors rather than attempting to evaluate conditions against natural sources (Emery et al., 2003). This seems to hold particularly true for a large system like the CAWS where the constructed and regulated conditions are the foundation around which the biotic conditions have developed.

Within urban systems, bioassessment approaches are challenged by the definition of appropriate benchmarks for target conditions under the complex range of modifications and multiple stressors that limit aquatic potential (Barbour et al., 2007). There is an expanding base of literature evaluating the stressors imposed on large urban stream systems (Coles et al., 2004; Brown et al., 2005; Flotemersch et al., 2006; Wilhelm, 2002; Lyons et al., 2001). Studies that have evaluated large urban systems have identified a large number of confounding impacts that include riparian and in-stream habitat loss, landscape fragmentation, impervious surface expansion, reductions in water quantity and quality, and numerous other effects that result in a degraded aquatic community (Booth et al., 2002; Kennen et al., 2005; Wilhelm, 2002). Reash (1999) states that the confounding impacts for urban systems described above are further blurred by establishment of lentic habitats created by damming.

Finally, bioassessment approaches can further support the interpretation of biological response to cumulatively increasing levels of stressors across a biological condition gradient (BCG), such as that depicted in Figure 2-2 (USEPA, 2005). The BCG (Figure 2-2) provides an example of how some key attributes of aquatic systems change in response to anthropogenic stressors regardless of assessment methods or geography (USEPA, 2005). The development of an appropriate, interpretable bioassessment program for the CAWS will allow for an evaluation of the many unique stressors within the system that have formed the limited biotic gradient of conditions across the system.

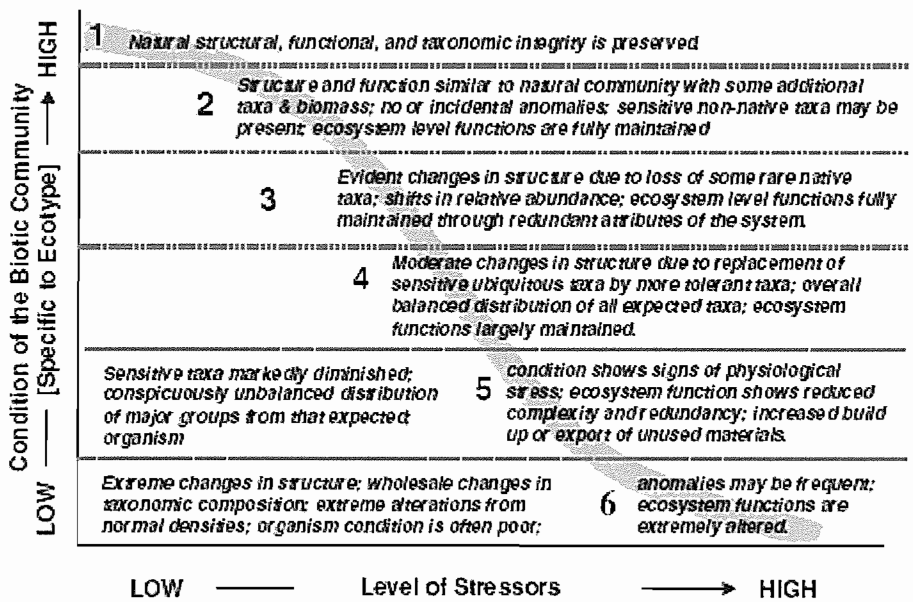

Figure 2-2: Relationship of Biological Response to Increasing Condition Stressors (from EPA, 2005).

2.2 IMPORTANCE OF HABITAT ASSESSMENT

As depicted in Figure 2-1 (Karr and Yoder, 2004), aquatic habitat is one of the five key components forming biological integrity and ecological health of aquatic systems. Although these factors are collectively important, habitat can be the factor most limiting aquatic community potential, and the existing conditions are usually the result of both hydrogeomorphic features and anthropogenic alterations (Rankin, 1995). Habitat assessments are a critical component of the bioassessment toolkit because they can explain much of the variation in biological diversity within a system, aid in the classification of reaches, identify disturbance gradients and effect, and can be used as a basis for restoration activities (Flotemersch et al., 2006). Habitats in large rivers tend to have long histories of physical degradation that provide a limited gradient of impacted conditions that illustrate the importance of characterizing habitats in these unique environments (Flotemersch et al., 2006).

Rankin (1995) identifies seven essential components of any habitat assessment index and Table 2-1 expands on functional applicability of these identified components as they apply to the CAWS.

Table 2-1: Essential Habitat Assessment Index Components (Rankin, 1995)

Habitat Component (Rankin, 1995)	Summary of Functional Value to Biota	CAWS Relevance
Substrate Type and Quality	The type and composition of substrate determines the quality of spawning habitat and cover for many fish species as well as influences benthic macroinvertebrate composition and production (McMahon et al., 1996). Fine substrates resulting from sedimentation are generally considered an important source of degradation of aquatic communities (Rankin, 1995). Waters (1995) recognizes the relationship between sedimentation and reduced macroinvertebrate availability for fish production, but states that research on the direct link between poor substrate quality and fish production is lacking. However, Waters (1995) states that the general relationship between benthic macroinvertebrates and fish production is well established.	The bed of much of the CAWS is cut through solid rock (most of the CSSC and Calumet-Sag Channel) or dug through consolidated silt and clay deposits which have lower pore space and interstices compared to natural silt beds. On top of this, inflows of storm runoff deposits fine sediment from the urban drainage area. Thus, the substrate in the CAWS is less ecologically functional than similar substrate in natural systems.
In-stream Physical Structure and Cover	The in-stream physical structure has a significant influence on aquatic organisms and its importance is well documented for both fishes and macroinvertebrates (Rankin, 1995; McMahon et al., 1996). McMahon et al. (1996) describe numerous examples of structure and cover types and state that cover preferences should be identified based on the species under study.	The constructed nature of the CAWS (for navigation and effluent conveyance) has eliminated much of the cover within the system. High turbidity prevents direct observation of cover in the system.
Channel Structure/ Stability/Modification	Modifications of channels alter stream flow, aquatic biota and many habitat characteristics (Rankin, 1995). Such changes have resulted in biotic effects to fisheries recruitment and trophic assemblages (Rankin, 1995). Aquatic organisms have been dramatically affected by channel alterations associated with navigational construction and maintenance (Wolter and Arlinghaus, 2003). The degree of channel alteration should be used as a measure of influence on the biotic expectations (Flotemersch et al., 2006; Reash, 1999).	Most of the CAWS have been constructed for navigation and effluent conveyance. This has resulted in generally uniformly shaped channels that are long and straight.

Table 2-1 (continued): Essential Habitat Assessment Index Components (Rankin, 1995)

Riparian Width/Quality	Typically, riparian areas play an important role in defining channel morphology, controlling stream temperature and creating and maintaining fish habitat (McMahon et al., 1996). The scale of riparian influence on rivers is associated with the river size, that is, smaller rivers are more influenced by the effects of riparian vegetation than larger rivers (Giller and Malmquist, 1998). Riparian disturbance effects appear to be better predictors of adverse biotic affect as their scale increases, rather than immediately adjacent to disturbed sites (Rankin, 1995). Common benefits of well developed riparian vegetation include buffering of surface generated nutrients, stabilization of stream banks and decreased sedimentation, provision of organic inputs, shading of water, and woody material recruitment (Rankin, 1995; Giller and Malmquist, 1998).	The width and quality of riparian areas across the CAWS has had no role in channel development. The maintenance of the channel for conveyance and navigation results in the removal of debris typically considered to be important to riparian habitat.
Bank Erosion	Bank erosion tends to be associated with riparian vegetation disturbance and erosion can contribute to sedimentation (Rankin, 1995; McMahon et al., 1996). Navigation generated sheer stress and wave action can increase bank erosion where bank stabilizing features are absent (Weigel et al., 2006). The adverse effects to biota from bank erosion are similar to those described for substrate and riparian conditions previously.	Bank erosion within the CAWS is generally limited because of the armoring and constructed nature of the system.
Flow/ Stream Gradient	Stream flow characteristics influence many aquatic habitat attributes (Rankin, 1995). Hill (Rankin, 1995), described four flow regimes that maintain physical and biological resources in stream systems: 1) flood flows, 2) overbank flows, 3) in channel flows for physical habitat function, and 4) in channel flows to meet biota requirements. Flows that are altered by anthropogenic means have been shown to strongly influence fish assemblages (Rankin, 1995). Systems regulated by locks and dams for navigation flows create impounded conditions that can favor lentic species (Sheehan and Rasmussen, 1999).	The flow and hydraulic gradient within the CAWS is controlled and regulated by the Lockport Powerhouse and Lock. The average hydraulic residence time within the CAWS is over 8 days, suggesting very low flow conditions.
Riffle-Run/ Pool-Glide Quality/ Characteristics	Geomorphic channel units (riffles, runs, pools, etc.) are fluvial habitat types that describe scouring, channel shape and overall habitat patterns in rivers and streams (Flotemersch et al., 2006). Lobb and Orth (Rankin, 1995) identified five guilds associated with large stream pool-riffle habitats that included 1) edge pool, 2) middle pool, 3) edge channel, 4) riffle, and 5) generalists. They suggest that the degradation of these habitats can eliminate or reduce the abundance of species within these guilds.	The constructed nature of the CAWS precludes the development of these fluvial habitat types.

The CAWS study area is entirely composed of nonwadeable (also called boatable) waters. Many management programs have avoided evaluating nonwadeable waters because of the logistical difficulties in monitoring large bodies of water. Numerous programs attempt to apply wadeable approaches to nonwadeable systems, and other programs eliminate certain quantitative measures in lieu of qualitative assessments (Flotemersch et al., 2006).

2.3 AVAILABLE APPROACHES FOR HABITAT ASSESSMENT

Most of the waterways in the CAWS are not rivers per se; they are large, nonwadeable, lotic waters. Because they are wide, deep channels conveying flowing water, they resemble large rivers. However, it is important to note that, most of the time, water moves through the CAWS at extremely low velocities, making them substantially different than natural rivers. However, the nearest analogies for studying such waters come from the study of large rivers and the scientific literature on the study of large rivers was reviewed for this study.

Several approaches are available for large river habitat assessment. The selection of an appropriate approach depends on the principle objective of the study, which is often either to conduct a thorough characterization of the physical habitat as a primary indicator of ecological condition or, when combined with biological surveys (as in this Study), to characterize those physical elements most likely contributing to the capacity of the system to support the survival and reproduction of biota (Flotemersch et al., 2006).

Most large rivers in North America have been modified to meet a range of anthropogenic uses and no single habitat evaluation approach is suitable for all large rivers because each is unique and heavily modified rivers contain a range of habitats not found in natural systems (Sheehan and Rasmussen, 1999). Flotemersch et al. (2006) provides a review of the major non-wadeable habitat assessment approaches in current use; these are summarized in Table 2-2. Screening of these approaches for use in this Study is discussed in the next section.

Table 2-2: Summary of Major Large River Habitat Assessment Protocols (Flotemersch et al., 2006)

Program	Protocol	Citation
Primary objective: characterizing long-term spatial and temporal patterns in habitat condition as its own independent indicator of ecosystem condition		
USEPA EMAP-Surface Waters	National and regional program for characterizing status and trends on ecological condition. Characterize seven general physical habitat attributes: channel dimensions, channel gradient, channel substrate size and type, habitat complexity and cover, riparian vegetation cover and structure, anthropogenic alterations, and channel-riparian interaction. Primarily quantitative measures.	Kaufmann, 2000
USGS NAWQA	National program to characterize water quality condition and develop an understanding of factors influencing quality. Quantitative measures taken to characterize habitat at 4 hierarchical scales: basin, segment, reach, and microhabitat	Fitzpatrick et al., 1998
Primary objective: evaluating habitat to understand biological condition		
Large River Bioassessment Protocol	Characterize 6 of 7 EMAP attributes: channel dimensions, channel substrate size and type, habitat complexity and cover, riparian vegetation cover and structure, anthropogenic alterations, and channel-riparian interaction. Reach length set to correspond to biotic assemblages being sampled. Semi-quantitative measures from six transects	Blocksom and Flotemersch, 2005; Flotemersch and Blocksom, 2005
Non-Wadeable Stream Habitat Index (NWHI)	A multi-metric index developed for characterizing habitat in Michigan non-wadeable streams and rivers. Features used in index include: riparian width, large woody debris, aquatic vegetation cover, sediment deposition, bank stability, substrate size, and off-channel habitat. Primarily quantitative measures.	Merritt et al., 2005; Wilhelm et al., 2005
Qualitative Habitat Evaluation Index (QHEI)	A multi-metric index developed for characterizing habitat in Ohio streams. Composed of six variables: substrate, in-stream cover, channel morphology, riparian zone and bank erosion, pool/glide and riffle/run quality, and gradient. Primarily qualitative scoring of metrics	Rankin, 1989

2.4 REVIEW AND SCREENING OF EXISTING INDICES

Relatively few habitat indices for large river systems have been developed due to the complex nature and sampling difficulties associated with the development and application of such indices (Wilhelm et al., 2005). The programs for which existing habitat indices were developed may have different objectives than the study at hand, resulting in an index that may not fit a particular application. When selecting an index for a particular purpose, there are several factors that should be taken into consideration. Some of these are identified below.

- ***Statistical basis for variable selection*** – Indices are developed by statistically referencing habitat variables against another variable set, such as biota. This is done to identify key habitat variables and to validate the index. The statistical basis for the index should be considered in determining whether its use is appropriate. For example, if the intent is to use the index to measure physical habitat to better manage fish, a habitat index that was developed by referencing fish data might be preferred.

- ***System basis for index development*** – Many indices are developed for a range of river types, from relatively unimpacted rivers to rivers that are heavily impacted by human activity. Many use indices rely on the relatively unimpacted rivers as reference reaches, which represent some desired condition.

- ***Variables included in the index*** – The variables included in a particular index should be examined to determine whether they are likely to provide an accurate measure of conditions within the system. If an index includes variables that are not appropriate for the system to be studied, the index may have limited utility in measuring variation throughout the system or over time.

- ***Quantitative vs. Qualitative Indices*** – Application of some indices relies on measured data, while some indices use more qualitative, subjective observations for scoring. Some use a mixture of measured data and observations. Because of the precision associated with measured data, it may be preferential to use a more quantitative index if field information is to be collected by many people and repeated over time for a system.

Using these considerations, each of the indices identified in the preceding section were reviewed to assess their applicability to the CAWS. A summary of the key qualities of these major large river habitat protocols was provided by Flotemersch et al. (2006) and is reproduced here as Table 2-3.

Table 2-3: Comparative Summary of Major Large River Habitat Assessment Protocols (Flotemersch et al., 2006)

		Protocol				
Category	**Variable**	USEPA EMAP	Large River Bioassessment Protocol (LR-BP)	MI Non-Wadeable Habitat Index	QHEI	USGS NAWQA
Quantitative		●		●		●
Semi- Quantitative			●			
Qualitative					●	
Anthropogenic Features		●	●			
Bank and Riparian		●	●	●	●	●
	Bank angle	●	●	●	●	●
	Bank height	●	●	●	●	●
	Riparian cond.	●	●	●	●	●
Geomorphology/Hydrology						
	Dimension	●		●	●	●
	Sinuosity				●	●
	Gradient	●	●	●	●	●
	Mean annual flow			●		●
	50% exc. flow			●		●
	Flow variability			●		●
	Off-channel habitat			●	●	
Overhanging/in-stream cover		●	●	●	●	●
	Aquatic vegetation	●	●	●	●	●
	Riparian cover	●	●	●	●	●
Sediment and substrate		●	●	●	●	●
Sediment and substrate	Size	●	●	●	●	
	Embeddedness	●	●	●	●	●
	Large woody debris	●	●	●	●	●
Water quality		●	●			
	Temperature	●				

After reviewing these habitat protocols, it was apparent that none of them were well-suited to the CAWS, for the reasons discussed in the following subsections.

2.4.1 Biotic Basis of Existing Protocols

Because one of the objectives of this Study was to determine what modifications to physical habitat in the CAWS would be required to improve aquatic habitat, use of a habitat evaluation protocol that was developed and validated for aquatic biota was important. Although all of the protocols reviewed here implicitly intend to evaluate habitat for aquatic biota, only the Ohio EPA Qualitative Habitat Evaluation Index

(Rankin, 2004) was found to explicitly reference fish in its development documentation (Rankin, 1989). No specific reference was found in the documentation of the USEPA EMAP (Kaufmann, 2000) or USGS NAWQA (Fitzpatrick et al., 1998) protocols. The large river bioassessment protocol (LR-BP) documentation (Blocksom and Flotemersch, 2005) references macroinvertebrates as the biotic basis, but not fish. The non-wadeable habitat index (NWHI) developed for Michigan (Wilhelm et al., 2005) was developed for fish but was statistically referenced to disturbance gradients in the selection of habitat variables and in validation.

2.4.2 System Basis of Existing Protocols

All of the habitat protocols reviewed for this Study were developed for rivers, using data from natural rivers. Although the documentation for some of the protocols discusses the fact that some of the systems used were modified by human activity, no reference was found to the inclusion of completely manmade channels, such as those that comprise approximately 75% of the CAWS. Rankin (1995) stated that indices need to be regionally calibrated, suggesting the importance of including local conditions in the selection or development of index protocols.

2.4.3 Variables Included in Existing Protocols

Many of the variables used in the existing protocols, including some of those listed in Table 2-3, are simply not applicable to a system like the CAWS, which was constructed largely for effluent conveyance and navigation and will continue to be operated for those purposes. Examples of the variables used in the existing protocols that are not useful in characterizing habitat in the CAWS include the following:

- Sinuosity is included in both the QHEI and the USGS NAWQA protocol, but sinuosity has either been intentionally removed from CAWS reaches or was never there to begin with, by design, to facilitate navigation and improve efficiency of effluent conveyance.

- Gradient is considered in all five of the protocols reviewed, but hydraulic gradient is controlled by downstream control works to maintain navigation and prepare the system for influxes of urban stormwater inputs, rather than by the centerline slope of the channel bed.

- Large woody debris is included in all five of the protocols reviewed, but it is deliberately removed from many areas in the CAWS to eliminate navigation hazards and provide unimpeded flows for effluent discharges.

- Embeddedness is included in the NWHI, LR-BP, and QHEI, but it is not applicable in the CAWS because the channels of the CAWS are not gravel-bed streams. Furthermore, the only major input of sediment to the system is relatively fine suspended sediment carried by storm water, which results in a substrate environment dominated by fine sediments deposited on bedrock or cohesive clay (glacial till).

All of the protocols reviewed include more than one key variable that is not useful in measuring habitat variation in the CAWS, because of the near complete absence of those variables. Because this 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 useful. This is a significant consideration in the use of these protocols on the CAWS. However, it is important to note that the near complete absence of habitat qualities like sinuosity or large woody debris is a significant habitat limitation in the CAWS.

2.4.4 Qualitative Nature of Existing Protocols

In general, a quantitative protocol was desired for this Study because of the desire to use the protocol to measure differences in a system that may not exhibit as much variation as a natural system and to distinguish potential change after habitat improvement projects. Furthermore, a quantitative protocol would be more consistently applied by multiple personnel over multiple time periods and would be less likely to be criticized for subjectivity. Of the protocols reviewed, one is qualitative (QHEI) and two have both qualitative and quantitative elements (USEPA EMAP and LR-BP). NWHI and USGS NAWQA protocols are quantitative.

2.4.5 Summary of Existing Habitat Protocol Review

The protocol review factors discussed in the preceding sections are summarized in Table 2-4.

Table 2-4: Summary of Existing Habitat Protocol Review

	Protocol				
Review Factor	**USEPA EMAP**	**LR-BP**	**MI NWHI**	**QHEI**	**USGS NAWQA**
Developed using fish data?	Unknown	No	No	Yes	Unknown
Developed for manmade systems?	No	No	No	No	No
Include variables that are nearly constant in CAWS?	Yes	Yes	Yes	Yes	Yes
Quantitative	Yes	Semi	Yes	No	Yes

Based on this review, all five of the large river habitat protocols have qualities that argue against their use in the CAWS. While three of the five are quantitative, all of them include multiple variables that are not useful in quantifying habitat quality and variability in the CAWS. None of the protocols reviewed were reported to include manmade systems in their development. Only one of them, the QHEI, was reported to be referenced to fish data in its development. To date, the only habitat index known to have been applied to the CAWS is the QHEI (Rankin, 2004). However, the applicability of this index to the CAWS is poorly suited for the reasons outlined above.

Recent guidance from USEPA (Flotemersch et al., 2006) suggests that, although there is a lack of consensus of a single most suitable habitat approach for nonwadeable systems, the selected protocol should:

1. thoroughly characterize the physical habitat as the primary indicator of ecological condition;

2. characterize physical elements that most likely contribute to the capacity of a system to support survival and reproduction of its biota; or

3. present a compromise between the two.

As described previously, biotic assessments provide a direct measure of the biological condition relative to integrity and integrate effects of multiple stressors in space and time. The linkage between habitat, biota and other aquatic components are already well established in the literature.

For these reasons, a system-specific approach to evaluating habitat that includes biota in the CAWS as part of the analysis was developed and is described below.

2.5 METHODOLOGY USED IN THIS STUDY

One of the stated objectives of this Study was to evaluate physical habitat conditions in the CAWS using a multi-metric index. Review of existing protocols for large flowing waters revealed significant limitations of existing protocols for use in the CAWS. Therefore the decision was made to develop a system-specific index for physical habitat in the CAWS. While none of the existing indices reviewed were well suited to use on the CAWS, it was noted that the procedures used in development of the Michigan NWHI (Wilhelm et al., 2005) could be readily adapted to the CAWS, with some modification. The process is outlined below.

The NWHI process used a logical, stepwise methodology to systematically reduce the field of potential habitat variables, similar to the process used in other studies (Blocksom and Flotemersch, 2005; Fitzpatrick et al., 1998; Hall et al., 1999). This variable reduction and screening process involves the following major steps:

- Screening of variables using professional judgment, as well as knowledge of the system under study and the objectives of the Study. This judgment-based process can be used to weed out variables that might not be applicable due to system conditions or that may be inappropriate in light of study objectives.

- Correlation analysis to identify and eliminate variables that are statistically redundant with other variables, based on the available data. This step involves use of a statistical comparison of the data, typically using Pearson's correlation test or Spearman's rho. Spearman's is sometimes preferred for ecological data because it is non-parametric and does not depend on the distribution of the habitat data.

- Once redundant habitat variables are eliminated using correlation analysis, principal components analysis is used to identify which of the remaining variables explain most of the variance of the data from the system.

The variable reduction process results in a reduced set of habitat variables that explain most of the variability in the habitat data and are relatively independent from each other. This process does not necessarily indicate whether the retained variables are most closely related to dependent biotic variables such as fish metrics or a fish index of biological integrity.

Once the final list of habitat variables is determined, the data for these variables are compared to biotic data to determine which habitat variables explain most of the variation in the biotic data. In this Study, multiple linear regression was used to compare the habitat data to fish metrics derived from system data. For the multiple linear regression in this Study, data from 2001 to 2007 were used. Various permutations of physical habitat data were compared to fish data using this approach to answer specific questions and to provide as clear an understanding as possible about the importance of physical habitat in the CAWS. Using this approach, one or more of the regression equations derived from the multiple linear regression can then be compared to an independent dataset to validate the regression model. 2008 fish data were used for this purpose.

The equation derived from the multiple linear regression can be used directly as a habitat index tool or it can be used as the basis of a habitat index and amended by supplemental data analyses and professional judgment. Inclusion of habitat variables in a habitat index that are not included in the original regression equation has been done (Wilhelm et al., 2005) based on professional judgment and correlation to biotic data. This is an important aspect of the index development process, which allows for application of specific knowledge of the system. The process outlined above is depicted schematically in Figure 2-3 and discussed in detail in Section 6 of this report.

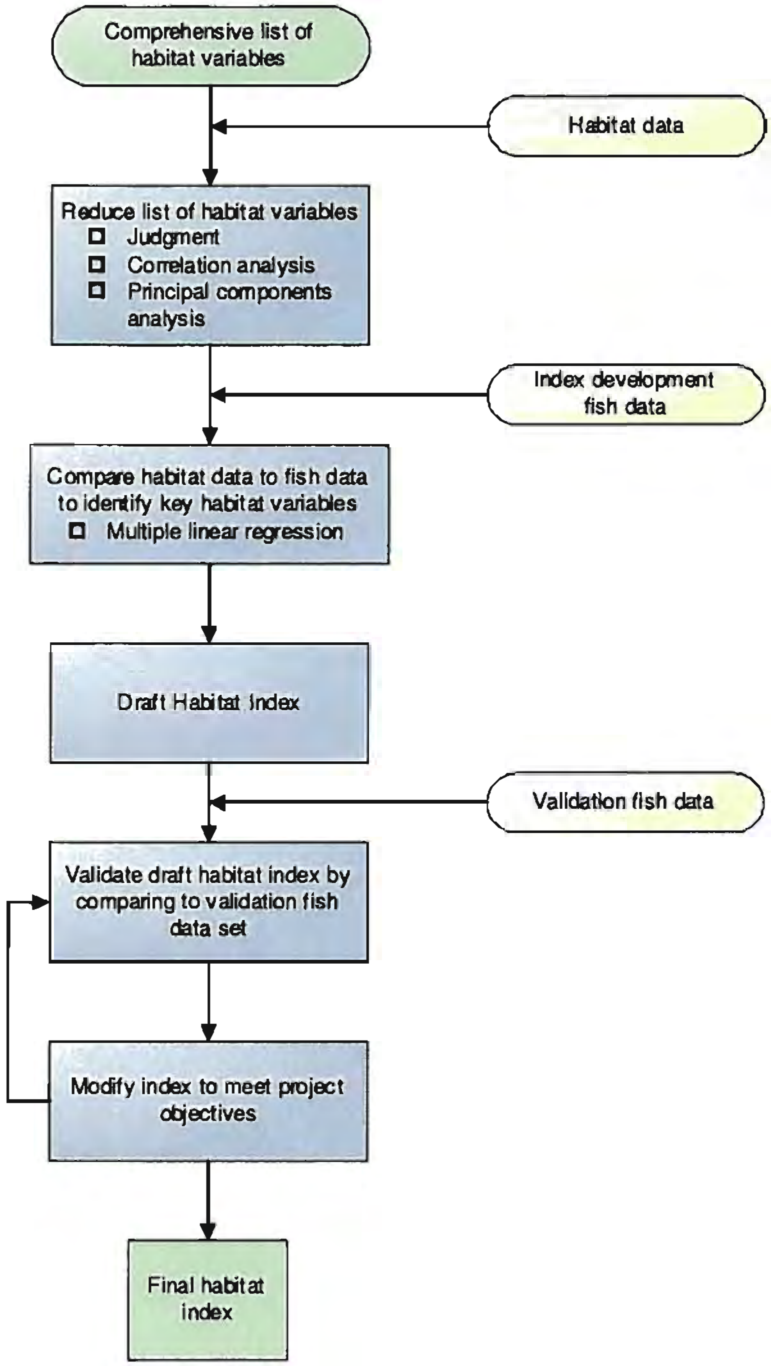

Figure 2-3: CAWS Habitat Index Development Process

2.5.1 Selection of Fish over Macroinvertebrates

Both fish and macroinvertebrate data have been collected by the District in the CAWS as part of the District's routine monitoring program. Each data set was evaluated to determine which dataset would provide the best response to habitat variables.

Flotemersch et al. (2006) states that the inclusion of macroinvertebrates into large river assessment programs is limited because of the general belief that macroinvertebrate assemblages are less diverse and more pollution tolerant in nonwadeable systems, primarily as a result of the dominance of fine sediments. Several other obstacles are cited including:

1. obtaining standardized and representative samples;
2. establishing a scale-appropriate and cost effective monitoring program;
3. identifying a reference condition given system alterations;
4. identifying specific stressors under the array of disturbances; and
5. the difficulty of sampling in navigable waterways.

An evaluation of the CAWS macroinvertebrate data was conducted to assess the structural and functional variation within the CAWS. The evaluations of the macroinvertebrate data collected by method (Hester-Dendy or ponar grab sampler), within stations, among stations, by reach or at a system level found similar results: a macroinvertebrate community dominated by pollution-tolerant taxa, represented by a few opportunistic Diperia (chironomidae) and non-insect taxa (oligochaetes) (Pott, 2009). These findings seem to support Blocksom and Flotemersch (2008) in that deep water habitats (>4 m) often have fewer sensitive taxa. Pott (2009) also suggests that legacy sediment contaminants may be affecting both sampling method results, although the Hester-Dendy samplers to a lesser degree are influenced by the high proportion of fine and resuspended sediments within the CAWS.

For the 2001-2007 analysis periods, the quantity and distribution of fish sampling events are approximately the same as macroinvertebrate sampling events. However, evaluation of the CAWS fish data found that this dataset varies more than the macroinvertebrate data, both spatially and temporally across the CAWS (Appendix A) and would likely provide a better indicator of habitat condition and response than the macroinvertebrates within the CAWS.

Fish assemblages are more commonly used in large river bioassessment programs than macroinvertebrates (Flotemersch et al., 2006). Data produced using appropriate fish sampling protocols can be used to assess use attainment, develop biological criteria, prioritize sample stations, provide impact assessments, and in status and trend analysis (Flotemersch et al., 2006). An assessment of the CAWS fish data (Appendix

A) finds a dataset with highly varied fish species and structure, which suggests that the CAWS fish dataset would be a better predictor of habitat responses than the macroinvertebrate data set. Based on this assessment, it was decided that the CAWS fish data would be used to assess the habitat index.

2.5.2 Development of Fish Metrics

Because the process for development of a system-specific habitat index for the CAWS required comparison to fish data, as described above, it was necessary to determine which metrics of fish would be appropriate for this purpose. While there is an Illinois index of biological integrity (IBI) for fish, it has some of the same limitations as the habitat indices reviewed for this Study, namely that it was developed for wadeable systems and may include metrics that are not applicable to the CAWS. So instead of using an existing fish IBI, CAWS fish data were used to identify the most representative fish metrics for the system.

The process of reviewing and screening the fish metrics followed the process used in development of many fish IBIs. Fish data collected by the District between 2001 and 2007 were used. These data were collected from 23 stations in the CAWS and represented 113 separate sampling events. The process involved review of fish metrics starting with an initial list of 46 fish metrics, identified from existing fish IBIs and published literature. CAWS fish data were reviewed to identify any CAWS-specific metrics that should be included. The metrics were then sequentially reduced as follows:

- Elimination of metrics that had no data (zero values);
- Elimination of metrics with very low ranges (2 or fewer species identified for the metric);
- Elimination of redundant metrics (using Pearson correlation tests); and
- Selection of metrics exhibiting greater variation in the CAWS.

This process reduced the number of fish metrics from 46 to 12, as summarized in Table 2-5.

Table 2-5: Fish Metrics Used in This Study

Fish Metric	Metric Name	Ecological Function Category
%DELT_(n)	% Diseased or with eroded fins, lesions, or tumors	Abundance and condition metric (ACM)
CPUE	catch per unit effort	Abundance and condition metric (ACM)
%LTHPL_(n)	% lithophilic spawners by count	Reproductive function metric (RFM)
%INSCT_(n)	% insectivores by count	Trophic function metric (TFM)
%TC_(wt)	% top carnivores by weight	Trophic function metric (TFM)
PRTOL	proportion of Illinois tolerant species	Indicator species metric (ISM)
LITOT	IL ratio of non tolerant large-substrate spawners	Reproductive function metric (RFM)
NMIN	number of IL native minnow species	Species richness and composition metric (SRC)
NSUN	number of IL native sunfish species	Species richness and composition metric (SRC)
GEN	IL ratio of generalist feeders	Trophic function metric (TFM)
%INT_(n)	% intolerant species by count	Indicator species metric (ISM)
%MOD_(wt)	% moderately intolerant species by weight	Indicator species metric (ISM)

A report was prepared to document the process of fish metric review and selection for this Study and is included as Appendix A of this report.

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3. DATA SUMMARY

Several types of data from multiple sources were used in this Study. These data included biotic data, water quality data, and physical habitat data. The nature and sources of these data are described in this section.

3.1 PHYSICAL HABITAT DATA

Efforts were made to acquire existing data where they were available. In many cases, existing data were incomplete or required field verification. Some new habitat variables had not been previously measured in the CAWS. To supplement existing data and address the data needs of this Study, crews were mobilized to the CAWS in the summer of 2008 for purposes of data acquisition. These efforts included:

- Between April 27 and May 21, boat-mounted crews from LimnoTech spent a total of eight days completing a visual inspection of the entire CAWS Study area, approximately 78 miles of waterways. This effort included a continuous digital video survey of all bank and riparian areas in the CAWS. This provided digital documentation of the banks within the entire Study area for use and reference throughout the Study.

- Between July 15 and August 15, LimnoTech field crews spent a total of ten days collecting field observations and measurements of physical habitat conditions at 28 400-meter stations in the CAWS Study area. Descriptions of the data collected during this effort are included in the discussion below. During this period supplemental bathymetric surveying was also completed using acoustic Doppler current profiling (ADCP) equipment in the North Shore Channel and North Branch Chicago River, where existing bathymetric data were unavailable.

In total, LimnoTech crews spent 18 days on the CAWS collecting physical habitat data for this Study. Supplemental data were acquired from a variety of sources including the District, the U.S. Army Corps of Engineers Rock Island and Chicago Districts, the Illinois State Geological Survey, the United States Geological Survey, and the Northeastern Illinois Planning Commission. Physical habitat sampling stations are depicted in Figure 3-1.

Several types of physical habitat data from the CAWS were collected for use in this Study, falling into the following general categories:

- Bank and riparian condition

- In-Stream and Overhanging Cover

- Channel bed condition

- Hydrology
- Anthropogenic Factors

Each of these data categories is discussed in greater detail below.

3.1.1 Bank & Riparian Conditions

Data on bank and riparian condition in the CAWS were obtained mainly from five sources for this Study: District physical habitat assessment forms; geographic land use data; aerial photography; visual inspection from the water; and detailed stations surveys. Each of these is described in more detail below.

District Physical Habitat Assessments

District personnel routinely perform physical habitat assessments (PHAs) during water quality and biota sampling on the CAWS. These data are typically recorded on a form and kept on file. For this Study, the PHA data forms from 2001 to 2007 were reviewed and transcribed into electronic format for inclusion in the electronic project database. Bank and riparian information available from the PHA forms included canopy cover, shore cover, and riparian land use.

Geographic Land Use Data

Riparian land use data for the CAWS was obtained from the Northeastern Illinois Planning Commission's 1:24,000-Scale 2001 Land Use Inventory for Northeastern Illinois. Analysis of this data set involved using geographic information system (GIS) software to create a 50 meter buffer on either side of the CAWS and classifying 30 adjacent land use types as industrial, urban, open space, or water as described below:

- Industrial land use included manufacturing, warehousing, industrial parks, and infrastructure such as freeways and waste facilities.
- Urban land use included residential areas and light commercial such as retail centers and office buildings.
- Open space included golf courses, nature preserves, and similar open grassland or forested areas.
- Water category was included only to describe when a station's edge met open water such as a ship slip or tributary.

The land use category with the greatest area within the buffer was then identified as the dominant land use and assigned a categorical number.

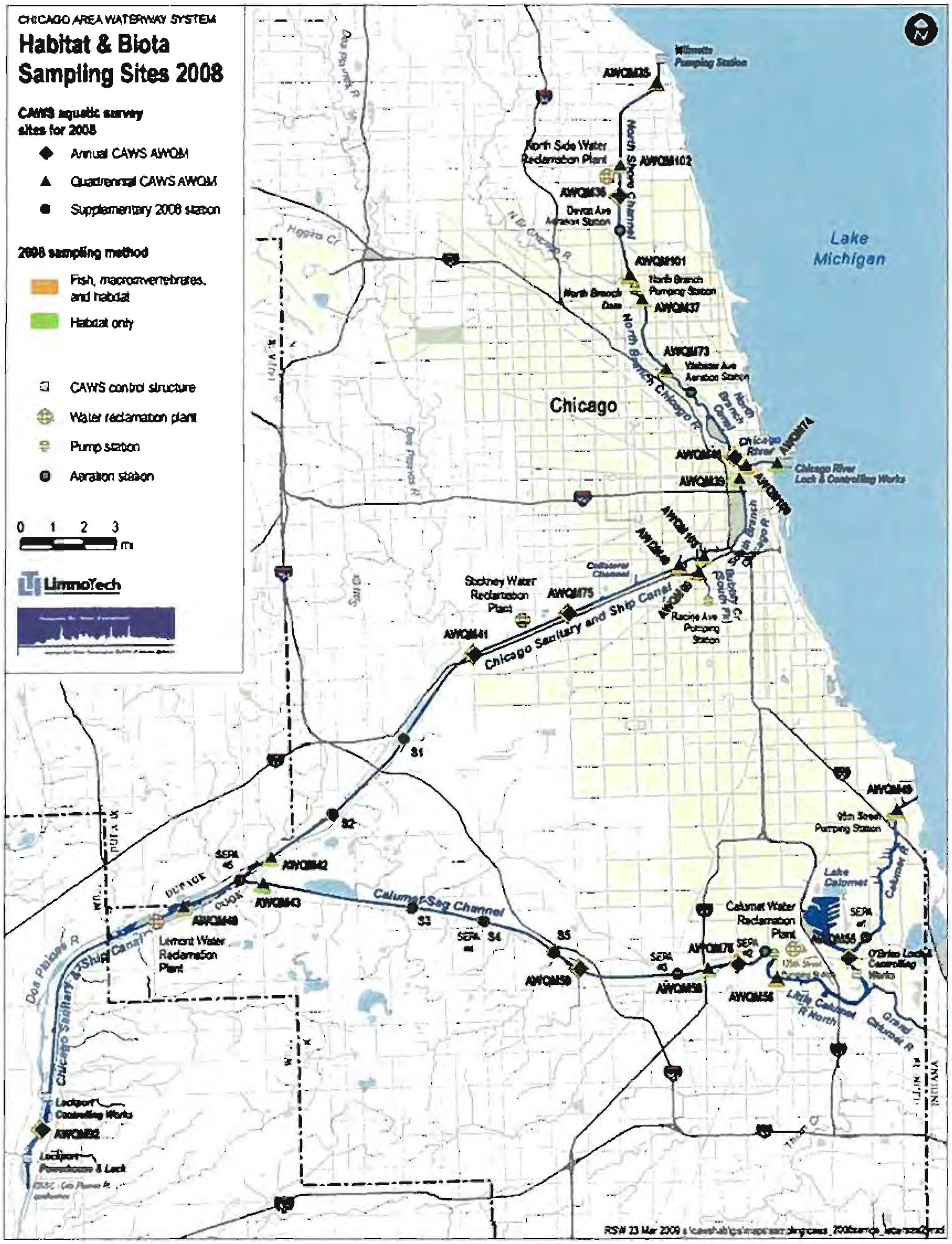

Figure 3-1: Habitat and Biota Sampling Stations in the CAWS.

Aerial Photography

Digital aerial photography (2005) was obtained from the Illinois Natural Resources Geospatial Data Clearinghouse of the Illinois State Geological Survey for the entire Study area. The digital aerial photography was imported into the project GIS and orthorectified with other spatial data. The aerial imagery was then visually inspected to provide supplemental information on riparian land use, riparian buffers, and open space. Percent of riparian vegetation was calculated in GIS by creating a 50 ft buffer adjacent to each station and expressing vegetated area as a percent of total area within the buffer. Aerial photography from 2005 was used to identify these vegetated areas. An example of the aerial photography used in this Study is provided in Figure 3-2.

Detailed Station Surveys

Detailed field surveys of 28 400 meter long sampling reaches were conducted during the 2008 field season to observe and quantify a range of bank and riparian conditions including the following:

- *Riparian vegetation* – The extent of riparian vegetation data for each of the 28 sampling stations was collected by measuring the length of vegetation on both banks of each 400 meter station reach. The types of riparian vegetation were not noted in the survey, but a continuous digital video record of both banks was recorded during the 2008 field season, which can be used to review the general vegetation types present along the CAWS.

- *Bank condition and angle* – Bank condition was recorded by type (earth, riprap, sheet pile, etc.) and the estimated bank angle was determined for each side of the reach (banks flatter than 45 degrees were assigned a value of one and banks steeper than 45 degrees were assigned a value of 2).

- *Overhanging vegetation* – Overhanging vegetation was determined at each station by measuring the length of the vegetated bank and the depth of overhang. The area of overhanging vegetation was calculated as the product of these measurements and expressed as a percentage of the total area of the station reach.

- *Bank pocket areas* – The number of small pocket areas in the banks that could provide refuge for fish was counted in each reach. This attribute represents concave, semi-sheltered portions of the bank with an overall face area (height x width) of at least one square meter, but less than five square meters, and a depth greater than a few inches.

- *Off-channel bays* – Very few true off-channel bays exist in the CAWS, but there are areas that are partially or fully secluded from the main channel that can perform the same function as off-channel bays by providing refuge for fish. These areas were counted in each sampling reach if they were greater than five square meters in plan area.

Some of these habitat attributes were supplemented by system-wide review as described below.

Visual Inspection of Bank and Riparian Conditions

As mentioned previously, a digital video survey of the entire CAWS Study area was conducted in 2008. Map-based viewing software was developed to facilitate use of the video. The video was subsequently inspected to classify and quantify bank conditions throughout the system. The entire length of both banks of the waterways was classified using 8 categories: steel sheet pile, concrete wall, stone block or bedrock wall, wooden walls, riprap, "natural" bank (earth bank with vegetation), marina (open marina or boat dock), and water (turning basin or tributary confluence).

A GIS shapefile of bank condition for the entire system was created from this visual record. Measurements in each category were expressed as a percentage of the total bank length at each station.

Figure 3-2: Example of Aerial Photography Used in the CAWS Habitat Evaluation and Improvement Study (Note: This figure shows the Webster Avenue Aeration Station in operation).

3.1.2 In-Stream and Overhanging Cover

In-stream and overhanging cover habitat within the CAWS was measured in the field at 28 stations during the 2008 field season. The parameters measured are described below.

Aquatic Vegetation

Aquatic vegetation was measured by direct visual observation by boat-mounted observers. Parameters measured included the following:

- Aquatic vegetation types – the number of different aquatic plant types observed in each 400-meter reach was recorded.

- Average macrophyte coverage – Macrophyte coverage (percent) was measured within representative 6-meter square field plots (minimum one per bank) within each station.

Coverage of each specific macrophyte type was not measured.

Secchi Depth

Secchi depth was measured using a standard Secchi disc at a minimum of three locations within each station.

Overhanging Cover

Depth (extent over water) and length (along banks) of shade cover were measured over the entire length of each bank within each of the 28 stations. Depth measurements were averaged for each reach based on discrete field measurements. Field measurements of channel width in each station were also collected for comparison to GIS-based width measurements and percent cover over the station reach was calculated using both field-measured channel width and GIS-measured channel width.

Submerged In-Stream Structure

Submerged in-stream structure that could provide cover for fish was not fully evaluated in this study because the high turbidity in most of the system prevented visual observation of conditions more than a meter below the surface. In efforts to overcome this limitation, two technologies were attempted in this Study: underwater digital video and side scan sonar. If successful, the imagery produced by these technologies would provide potentially valuable information on subsurface conditions, such as direct observation of submerged structures.

Underwater digital video was attempted at several locations in the system, but in reaches outside of the Chicago River, visibility was limited to less than 0.5 meter, making this technology impractical for use in the CAWS.

Side scan sonar was pilot tested at four reaches in the CAWS and although it showed promise in revealing subsurface structure and bed conditions, it was determined that the amount of data that would be required to validate the technology in the CAWS was not available and could not be practically collected within the timeframe of the Study. An example of the side scan sonar imagery from the CAWS is shown in Figure 3-3.

3.1.3 Channel Bed Conditions

Direct observation of bed conditions is not possible in the CAWS because of the depth and turbidity of the water. For this Study, information on bed conditions, including bathymetry and substrate size, was obtained from sediment grab samples and from electronic bathymetric surveys, as described below.

Bathymetry

Detailed bathymetric data for much of the CAWS were obtained from the Rock Island District of the U.S. Army Corps of Engineers (USACE), which has jurisdiction of the CAWS south of the Chicago River[1]. Bathymetric data were also obtained from the Illinois office of the U.S. Geological Survey (USGS). All bathymetry measurements were taken between 2001 and 2008. Soundings were used to generate a triangular irregular network (TIN) representation of bathymetry throughout the CAWS. Transects at upstream, center, and downstream locations for each station were sampled from the TIN. The Lockport normal pool elevation of 577.48 ft (NGVD 29) was applied as the water level for these stations. Figure 3-4 shows the extent of the various types of bathymetry used in this Study. Digital bathymetric data were imported into the project GIS for ease of use (Figure 3-5).

No digital survey data were available for the Chicago River and reaches north thereof, so LimnoTech conducted bathymetric surveys of sampling station reaches using a boat-mounted acoustic Doppler current profiler (ADCP) in July 2008, which provided accurate bathymetric measurements at the sampling stations. Depth soundings from the National Oceanic and Atmospheric Administration (NOAA) were used to extrapolate the ADP across the reaches as necessary.

[1] The Chicago District of the US Army Corps of Engineers has jurisdiction of the CAWS north of the Chicago River. Although the Chicago District confirmed that recent bathymetric data had been collected from their portion of the CAWS, the Chicago District denied LimnoTech's request for the data, stating that the data are provisional.

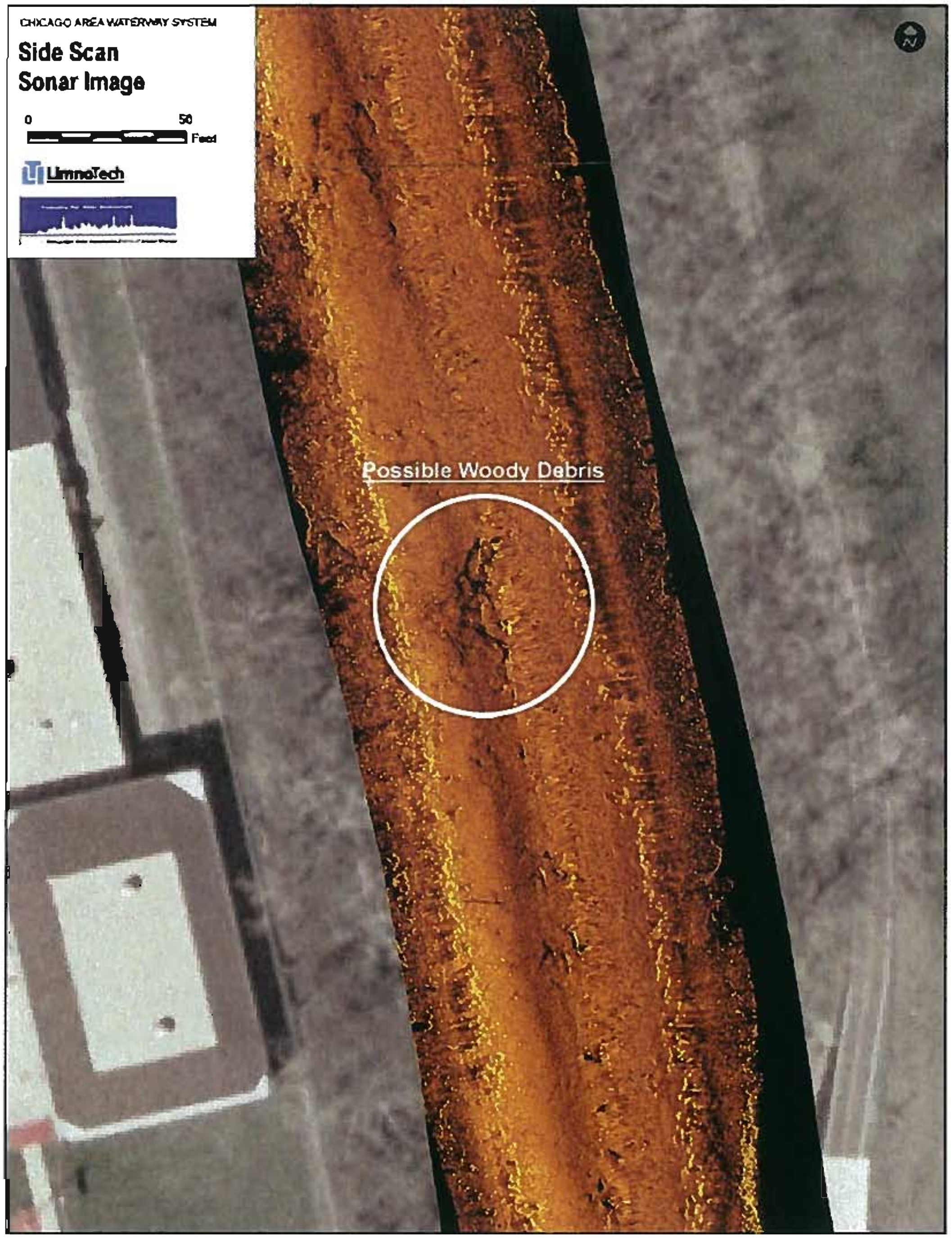

Figure 3-3: Example of Side Scan Sonar Imagery from the CAWS, Overlain on Aerial Imagery (Imagery Collected in Upper North Branch of the Chicago River).

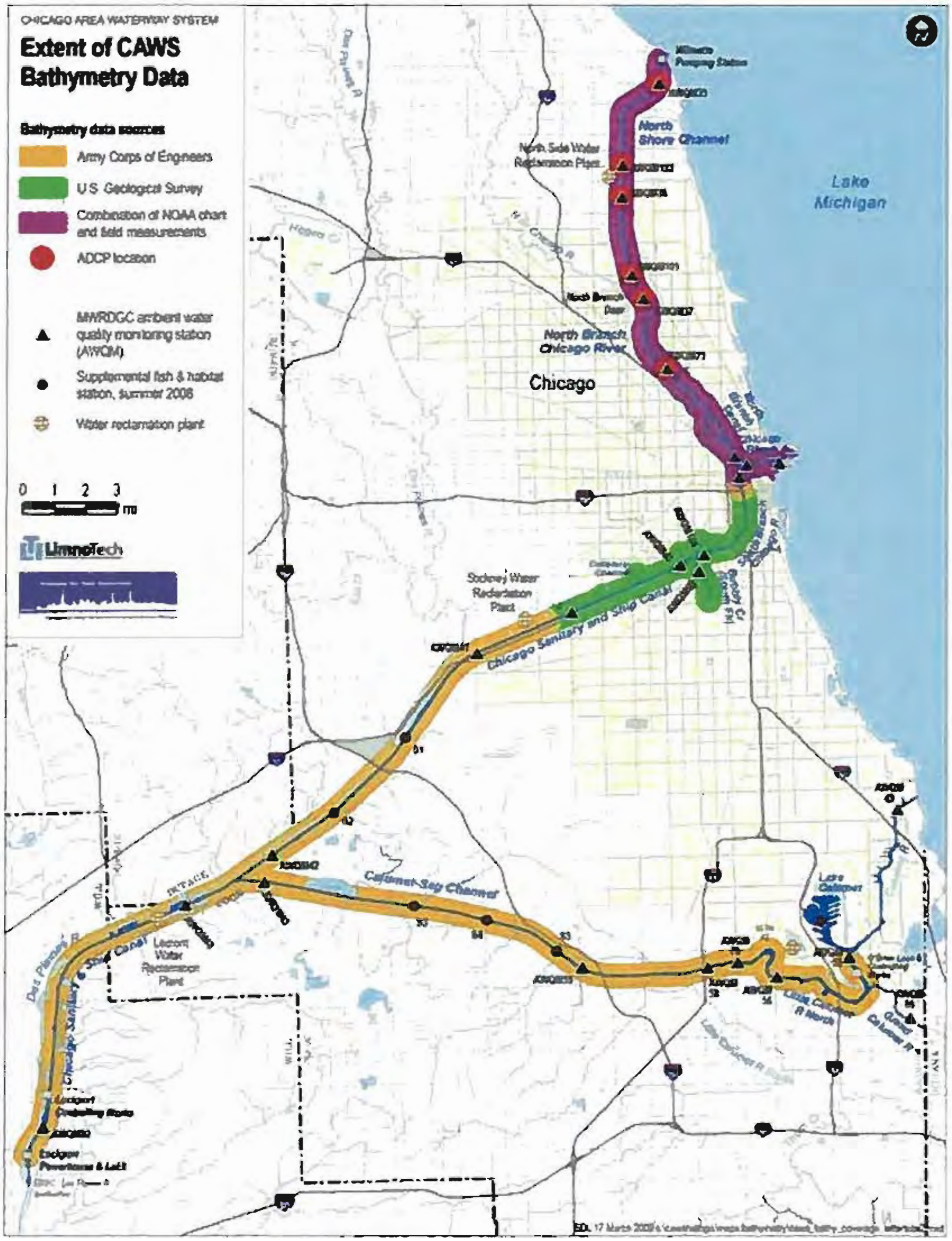

Figure 3-4: Bathymetric Data Used in the CAWS Habitat Evaluation and Improvement Study.

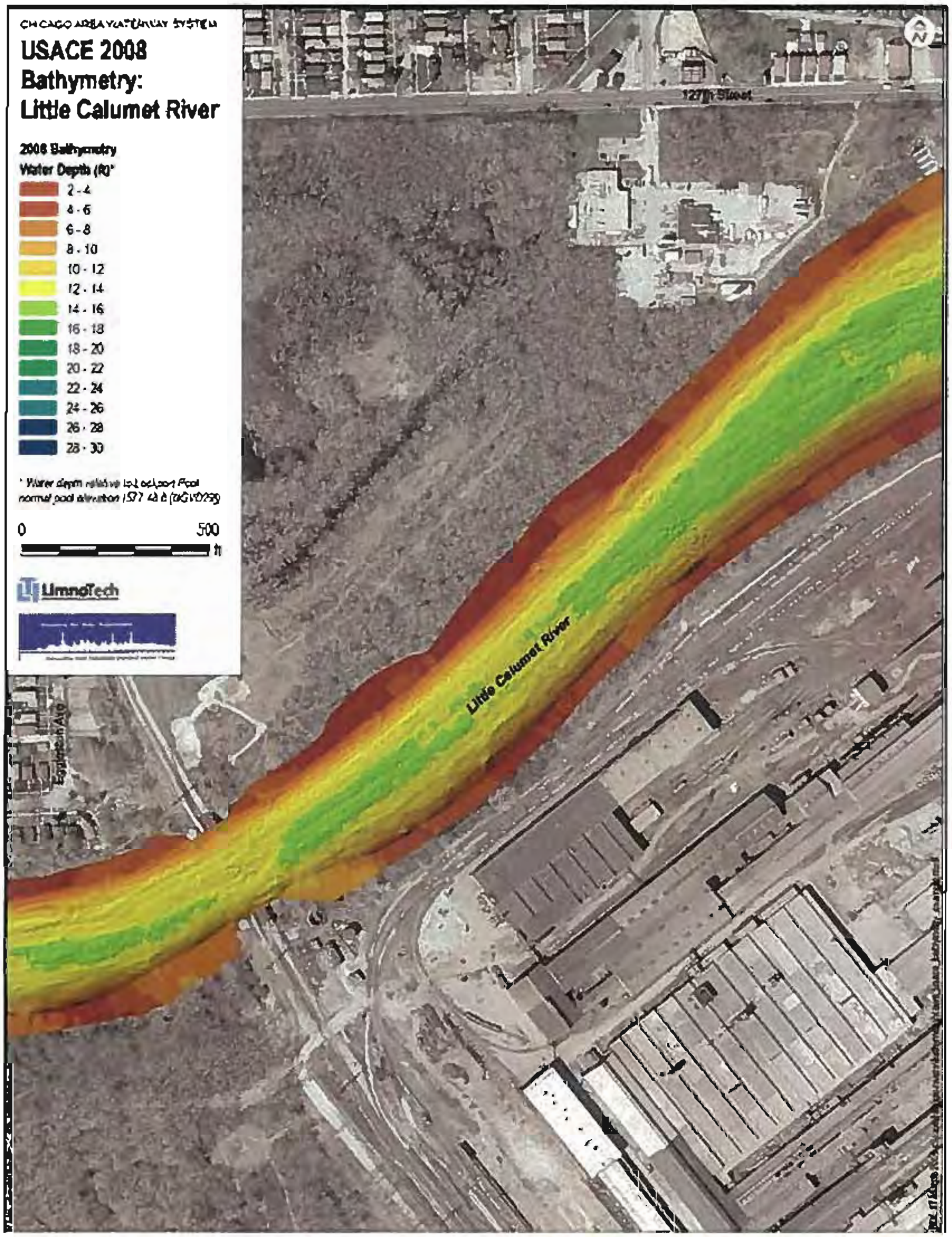

Figure 3-5: Example of CAWS Bathymetric Data in GIS.

Once data to describe bathymetry at each station was assembled, channel transects were used to develop the following geomorphology variables; average depth, maximum depth, top width, bottom width (width at 85% of the maximum depth), cross-sectional area, wetted perimeter, hydraulic radius, ratio of top width to bottom width, and ratio of top width to average depth. These variables were averaged over the three transects at stations with detailed bathymetric data.

Substrate

Physical sediment characterization in the CAWS bed conditions is routinely performed by the District as part of the physical habitat assessment portion of the ambient water quality monitoring (AWQM) program. This involves use of a 6 in. x 6 in. petite ponar dredge to obtain a sediment grab sample at mid-channel and side-channel locations at both the upstream and downstream ends of each station. Samples are characterized by estimating percent composition of the following:

- plant debris
- organic sludge
- inorganic silt
- clay
- sand
- gravel
- cobble
- boulder
- bedrock/concrete (hardpan)

In addition, depth of fines is measured using a one-inch diameter fiberglass leveling rod pushed as far as possible into the bed sediment. Since 2002, the District has conducted these assessments at 23 locations in the CAWS. Eight of these locations have been assessed annually, while the rest have been assessed once every four years. In 2008, LimnoTech performed additional physical sediment characterization at five supplemental stations as part of this Study.

The physical sediment data gathered by the District were used to develop twelve sediment and substrate variables. The plant debris, inorganic silt, and organic sludge parameters were averaged over the four sites assessed at each station and averaged over all years with available data. The rest of the sediment types were handled by keeping the mid-channel and side-channel assessment sites separate. These samples were considered to be deep substrate and shallow substrate, respectively. The bedrock/concrete parameter was averaged over these respective sites and over time to create percent hardpan-deep and percent hardpan-shallow variables for each station.

Sand and clay parameters were added together and averaged to create percent sand and fines-deep and percent sand and fines-shallow variables. Gravel, cobble, and boulder parameters were added together and averaged over assessment sites and time to create deep and shallow variables representing large substrate.

3.1.4 Hydrology

Flow data in the CAWS is recorded by USGS gaging stations located downstream from each of the three major diversion control structures. The North Shore Channel station at Wilmette monitored daily discharge from 1996 to 2003. The Chicago River station at Columbus Drive provided periodic discharge data with a continuous daily period of record in water year 2006. The Calumet River station downstream of the O'Brien Lock monitored daily discharge from 1996 to 2003. Flow was also monitored at the downstream end of the system at Romeoville Road, upstream of the Lockport Controlling Works. This location provided flow data from 1984 to 2005 but has been replaced by a station near Lemont, IL. The Lemont gage is currently the main data source for monitoring the Lake Michigan diversion, with daily discharge data available from 2004 to the present. Gaging stations also exist on several major tributaries to the CAWS. The gage data are useful for describing hydrologic conditions at a few locations, but cannot provide detail for individual AWQM stations.

The USGS gages operated at various locations in the CAWS were not well-located to provide hydrologic data at the habitat and biota sampling stations used in this Study, nor were they operated concurrently with all the years of data used in this Study (2001-2008). As an alternative for attributing flow and velocity variables to individual AWQM stations in this Study, output from a calibrated hydraulic model was used. In 2000, the District entered into an agreement with Marquette University to develop a hydraulics and water-quality simulation model to the CAWS. The model, called DUFLOW, has been used to investigate the effects of different management options in the CAWS. The model was calibrated and validated by the Institute for Urban Environmental Risk Management, Marquette University in 2003. Hourly stage measurements at the USGS Romeoville gage as well as the District hourly stage gages at Sag Junction, Willow Springs Road, and Western Avenue were used for hydraulic/ hydrologic calibration of the model. Model inflow is obtained from many different sources including USGS gage data at the three major inlets from Lake Michigan, as well as major tributaries. Operating records from water reclamation plants, pump stations and industrial sources were also used to calibrate the model. Additional ungaged tributaries and CSO sources were estimated.

The DUFLOW model divided the CAWS into 291 discrete segments. The segment nearest each AWQM station was selected to represent hourly flow and velocity output. Unsteady flow output from May 1, 2002 to September 23, 2002 was obtained and analyzed in order to develop variables which could capture spatial variability in flow and velocity. Six hydrologic variables were initially computed for the AWQM stations in the CAWS. Flow and velocity variables included:

- 50% exceedance flow
- mean annual discharge
- flashiness index (ratio of 10% exceedance flow to 90% exceedance flow)
- average velocity
- maximum velocity
- mean velocity to mean depth ratio.

The intent of both the flow and velocity variables was to measure magnitude regardless of flow direction. As the conditions in the CAWS cause occasional flow reversals, the model output for flow and velocity was handled using absolute values to prevent negative velocities from affecting the intent of the variables.

It should be noted that hydrologic parameters such as those listed above cannot be reliably estimated from a five-month modeling simulation. Such parameters usually require decades of data to quantify accurately. However, such data are not available for every monitoring location in the CAWS and the alternative to relying on the five-month modeling simulation was to exclude hydrologic variables altogether. For purposes of this study, it was deemed more useful to use approximations based on the model output than to move forward with the habitat analysis without any flow variables.

3.1.5 Anthropogenic Factors

Although not true physical habitat variables in the traditional sense, a number of anthropogenic factors were considered in this Study. This was deemed appropriate because of the constructed nature of the CAWS and the fact that the primary uses of the system (effluent conveyance, navigation, flood control) are anthropocentric. Some of these major anthropogenic factors are discussed below.

3.1.5.a Navigation

Navigation data for the CAWS is maintained by the U.S. Army Corps of Engineers (USACE) Waterborne Commerce Statistics Center. Vessel movements and commodity tonnages are reported by vessel operators to the USACE. Within the managed portion of the CAWS, vessel movements are summarized for each of 4 reaches:

- Chicago River & North Branch Chicago River (South of the North Branch Turning Basin)
- South Branch Chicago River
- Chicago Sanitary & Ship Canal
- Calumet-Sag Channel & Little Calumet River North

Detailed movements within these reaches are not available. The available data were compiled and analyzed by the Great Lakes Fishery Commission (GLFC) as part of a recent study on ecological separation of the Mississippi River and the Great Lakes (Brammeier et al., 2008). Several navigation metrics were obtained but for purposes of this Study it was decided to use two variables: through-upbound tonnage and through-downbound tonnage. These variables were reported in annual tonnages for 2001 through 2004. Because the goal was to have a relative measure of commercial navigation traffic, the variables were summed and assigned as a single variable in the database. All reaches within the managed portion of the CAWS without vessel tonnages reported were assumed to be free of heavy commercial traffic.

3.1.5.b Sediment Chemistry

Organic and inorganic sediment chemistry data on the CAWS have been collected by the District since 2002, with the exception of 2004. These data are for surface grab samples collected using a petite ponar dredge at the center and side of the 21 AWQM stations. Samples are typically analyzed for over 130 organic and inorganic parameters.

Sediment chemistry data on the CAWS were also obtained from the Great Lakes National Program Office (GLNPO) and the U.S. Army Corps of Engineers. GLNPO took sediment cores and grab samples at about 10 locations on the Chicago River, South Branch Chicago River, North Branch Chicago River, and South Fork in 2000. Samples were analyzed for about 60 parameters. USACE data covered about 18 locations on the South Fork in 2004 with sediment cores and grab samples. Samples were analyzed for about 165 parameters.

3.1.5.c Manmade Structures

Manmade structures (bridge abutments, dolphins, piers) can have both positive and negative impacts on aquatic life (Duffy-Anderson, et al. 2003). In some cases, these structures can provide shelter for fish or organisms on which fish feed. However, manmade structures are not usually built to serve the purpose of providing habitat and some other aquatic use is usually associated with them, such as navigation, transportation, and commerce. These other uses may have detrimental impact on aquatic life and if these impacts outweigh the benefits of the structures, the structures become an undesirable habitat attribute. The presence of manmade structures (Figure 3-6) in the channel in the channel was recorded at each sampling station in this study.

Figure 3-6: Examples of Manmade Structures (Dolphins) on the Chicago Sanitary and Ship Canal Near AWQM 41.

3.2 BIOTIC DATA

Biotic data used in this study included fish and macroinvertebrate data collected by the District between 2001 and 2008, as well as supplemental fish and macroinvertebrate data collected specifically for this Study in 2008. These data and their uses are discussed below. Sampling stations for biota are shown in Figure 3-1.

3.2.1 Fish Data

Fish data collected within the managed portion of the CAWS were collected using boat electrofishing procedures, because the system is almost entirely nonwadeable. Field procedures followed standard electrofishing protocol, using direct current shocking only, and only two netters collecting stunned fishes. Station sample lengths are 400 meters and include sampling primarily along the banks. Collected fishes are generally identified to species in the field, measured for length, and weighed. Each collected fish is also examined for disease, parasites or other anomalies and recorded where observed. All field identified fishes are then returned live to the waters. Minnows and other fishes that are not clearly identified in the field are preserved in 10 percent formalin and identified, weighed and measured in the lab.

The number of fish sample stations within the CAWS has varied by year for the 2001-2008 period. Table 3-1 describes fish sample locations, by date, within the CAWS. Twenty eight stations are included in the District sampling program, within the managed portion of the CAWS. In 2008, five supplemental stations were added to attempt to capture additional habitat variation in the system that may not be captured by the existing sample stations. The total number of sample station events during the 2001-2008 sample period totaled 101. The 2001-2007 fish dataset was used to build and assess the habitat index against (that is, to calibrate the index), while the 2008 dataset was used as the validation dataset.

Table 3-1: CAWS Fish Sampling Events Used in This Study

Station Description[2]	AWQM No.	2001	2002	2003	2004	2005	2006	2007	2008
NSC at Central Street	35	9/24/01				7/20/05			7/25/08
NSC at Touhy Avenue	36	9/26/01	7/31/02	7/24/03	9/29/04	7/21/05	7/10/06	7/12/07	11/6/08
NSC at Foster Avenue	101	9/27/01				9/8/05			7/25/08
NSC at Oakton Street	102	9/25/01				7/20/05			
NBCR at Wilson Ave	37	10/1/01				9/7/05			
NBCR at Diversey Pkwy	73	10/3/01				9/6/05			7/25/08
NBCR at Grand Avenue	46	10/2/01	8/1/02	7/23/03	8/27/04	7/18/05	7/11/06	7/11/07	11/5/08
LCR at Indiana Avenue	56			9/29/03				7/30/07	7/26/08
LCR at Halsted Street	76	9/12/01	9/16/02	9/29/03	9/30/04	9/27/05	7/21/06	7/31/07	10/28/08
CSC at Route 83	43			7/30/03				9/14/07	
CSC at Ashland Avenue	58			9/5/03				8/1/07	
CSC at Cicero Avenue	59	9/14/01	9/17/02	7/31/03	8/31/04	9/29/05	7/24/06	8/2/07	10/17/08
CR at Lake Shore Drive	74		8/2/02				7/26/06		
CR at Wells Street	100		8/21/02				7/27/06		7/24/08
SBCR at Madison St	39		8/27/02				7/28/06		
CSSC at Damen Ave	40		8/19/02				8/30/06		7/24/08
BC at Archer Avenue	99		8/20/02				9/5/06		7/24/08
SBCR at Loomis Street	108		8/26/02				9/12/06		
CSSC at Harlem Ave	41	9/7/01	9/3/02	7/21/03	8/24/04	8/26/05	8/21/06	7/16/07	10/29/08
CSSC at Route 83	42		8/28/02				8/31/06		
CSSC at Stephen Street	48		9/10/02				8/28/06		7/23/08
CSSC at Cicero Ave	75	9/4/01	8/29/02	7/18/03	8/23/04	8/22/05	8/29/06	7/17/07	10/29/08
CSSC at Lockport (16th St)	92	9/4/01	9/11/02	7/29/03	8/30/04	9/15/05	7/25/06	7/10/07	10/9/08
CSSC at Bedford Park	-								7/23/08
CSSC at Willow Springs	-								7/23/08
CSC at Palos Hills	-								7/17/08
CSC at Worth & Palos Hts	-								7/22/08
CSC at Alsip	-								7/26/08

3.2.2 Macroinvertebrate Data

Macroinvertebrate data collected within the CAWS were collected using two methods: artificial substrate samplers (Hester Dendys or HDs) and Ponar grab samplers. HDs were deployed at each station between May and June. Each station contains three side channel and three mid- channel HDs that are cabled to river anchors. HDs are deployed between 7 and 14 weeks. Retrieved HDs are collected using 250-micron mesh nets and HDs are stored in 10 percent formalin solution for

[2] NSC = North Shore Channel; NBCR = North Branch Chicago River; SBCR = South Branch Chicago River; CSSC = Chicago Sanitary and Ship Canal; CSC = Cal-Sag Channel; CR = Chicago River; BC = Bubbly Creek; LCR = Little Calumet River

processing. Ponar samples were collected in triplicate at side and center locations at each station. Field samples are filtered through 250-micrometer sieve buckets and stored in 10 percent formalin solution for processing. A summary of the macroinvertebrate sampling events is presented in Table 3-2.

Table 3-2: CAWS Macroinvertebrate Sampling Events Used in This Study

Station Number	Station Description	2001	2002	2003	2004	2005	2006	2007
99	Bubbly Creek at Archer Avenue		X				X	
58	Calumet-Sag Channel at Ashland Avenue			X				X
59	Calumet-Sag Channel at Cicero Avenue	X	X	X	X	X	X	X
43	Calumet-Sag Channel at Route 83			X				X
74	Chicago River at Lake Shore Drive		X				X	
100	Chicago River at Wells Street		X				X	
75	Chicago Sanitary and Ship Canal at Cicero Avenue	X	X	X	X	X	X	X
40	Chicago Sanitary and Ship Canal at Damen Avenue		X				X	
41	Chicago Sanitary and Ship Canal at Harlem Avenue	X	X	X	X	X	X	X
92	Chicago Sanitary and Ship Canal at Lockport (16th St)	X	X	X	X	X	X	X
42	Chicago Sanitary and Ship Canal at Route 83		X				X	
48	Chicago Sanitary and Ship Canal at Stephen Street		X					
76	Little Calumet River at Halsted Street	X	X	X	X	X	X	X
56	Little Calumet River at Indiana Avenue			X				X
73	North Branch Chicago River at Oiversey Parkway	X				X		
	North Branch Chicago River at Fullerton Avenue				X	X		
46	North Branch Chicago River at Grand Avenue	X	X	X	X	X	X	X
37	North Branch Chicago River at Wilson Avenue	X				X		
35	North Shore Channel at Central Street	X				X		
101	North Shore Channel at Foster Avenue	X				X		
102	North Shore Channel at Oakton Street	X				X		
36	North Shore Channel at Touhy Avenue	X	X	X	X	X	X	X
108	South Branch Chicago River at Loomis Street		X				X	
39	South Branch Chicago River at Madison Street		X				X	

Processing of macroinvertebrates in the laboratory varies by collection method. HDs are disassembled, cleaned and sieved through a 250-micrometer sieve. Side samples are combined as a single sample and mid-channel samples are combined as a single sample so each station is represented by a side and mid-channel HD sample. Ponar samples are further rinsed and screened in the laboratory using a 250-micrometer sieve, The triplicate samples are combined into a single side sample and a single mid-channel sample. All species identifications are made to the lowest practical taxonomic classification. Representative samples of chironomid head capsule deformities are determined as part of the standard procedures for the datasets.

Processed macroinvertebrate data were analyzed by Baetis, Inc., under subcontract to LimnoTech, and were used to select appropriate macroinvertebrate metrics for the CAWS, compare collection methods, and evaluate deformities as related to water quality and contaminated sediment (Appendix B).

3.3 WATER QUALITY DATA

The water quality data used in this Study consisted of data collected by the District between 2001 and 2007. The District's water quality data collection program in the CAWS includes continuous monitoring of certain parameters from several locations in the CAWS, as well as discrete sampling of water quality as part of their annual water quality monitoring program. These data collection programs are summarized below.

3.3.1 Continuous Monitoring Data

The District currently deploys continuous dissolved oxygen (DO) monitors at 33 locations in the CAWS. These monitors collect hourly data and are serviced on a weekly schedule. A detailed discussion of the continuous DO monitoring (CDOM) program is presented in Minarik et al. (2008). The DO data are collected throughout the CAWS by the District using automated data collection monitors manufactured by YSI Incorporated (YSI) of Yellow Springs, Ohio. DO is measured hourly using the YSI Model 6920 or Model 6600 monitor. For this Study, CDOM data from 23 stations in the CAWS, collected between 2001 and 2007 were used. The locations of these CDOM stations are shown in Figure 3-7. In addition to DO data, the District's CDOM program also collects continuous data on specific conductance, pH, and temperature.

Figure 3-7: Annual Water Quality Monitoring (AWQM) Stations and Continuous Dissolved Oxygen Monitoring (CDOM) Stations in the CAWS.

3.3.2 Annual Water Quality Monitoring

In addition to their CDOM program, the District also conducts an ambient water quality monitoring (AWQM) program. There are 26 AWQM stations in the CAWS, as depicted in Figure 3-1. Water quality is regularly sampled at these stations in accordance with the AWQM Quality Assurance Project Plan (District, 2007). Sampling is conducted on a monthly basis for most parameters. The water quality parameters sampled for the AWQM program include:

- Field-measured parameters (temperature, pH);
- DO
- Turbidity
- Total phosphorus and nitrogen compounds (nitrate/nitrite, ammonia nitrogen, total Kjeldahl nitrogen);
- Sulfate;
- Total dissolved solids, suspended solids, and volatile suspended solids;
- Alkalinity, chloride, and fluoride;
- Total organic carbon;
- Phenol;
- Cyanide;
- Indicator bacteria (fecal coliform and E. coli);
- Chlorophyll;
- Total and soluble metals (arsenic, barium, boron, cadmium, calcium, chromium, iron, lead, magnesium, manganese, mercury, nickel, selenium, silver, and zinc); and
- Volatile organic compounds (benzene, toluene, ethylbenzene, xylenes).

3.3.3 Use of Water Quality Data in this Study

Water quality data were used to evaluate the relationship between water quality and fish in the CAWS, separate from physical habitat. The report describing the analysis of fish and water quality in the CAWS is included as Appendix C. DO data were also used in conjunction with key physical habitat variables identified from multiple linear regression analysis of habitat data, to evaluate the degree to which water quality data helped explain variability in fish data over physical habitat data alone. These analyses are discussed in Section 6 of this report. The findings of the analysis of fish and water quality in the CAWS are presented below and described in more detail in Appendix C.

- *Fish metrics are positively correlated to dissolved oxygen, but dissolved oxygen is a poor predictor of fish metrics.* A few fish metrics showed statistically significant correlation to observed dissolved oxygen concentration, with higher dissolved oxygen concentrations resulting in slightly better metrics. This result does not necessarily indicate that oxygen concentrations are the primary factor controlling fish health. The statistical maxim "Correlation does not imply causation" applies here. Furthermore, the r-squared values between fish metrics and dissolved oxygen concentration are relatively low for the most part (i.e. generally less than 0.2). It should be noted that this finding does not necessarily indicate that oxygen concentrations are an unimportant predictor of fish health. The dissolved oxygen concentrations used in these regressions do not fully represent the historical exposure of the sampled fish to oxygen. Fish are mobile, and may be exposed to dissolved oxygen concentrations significantly different that the ones reflected at the oxygen monitoring location during the time of fish collection.

- *In terms of ability to explain fish data in the CAWS, compliance with new standards is similar to compliance with existing standards.* Fish metrics from observations where standards were being attained were generally better than fish metrics where standards were not in attainment, but most differences were not statistically significant. In addition, fish metrics showed a positive correlation to the percent of time that standards were attained at a station. These findings hold for both the current and proposed standards, although the current standards showed a higher number of significant differences than do the proposed standards. This may imply that compliance with new standards may not be as good a predictor of fish health as compliance with existing standards.

- *Some fish metrics are positively correlated to temperature, but more poorly than with dissolved oxygen.* Relatively few fish metrics showed statistically significant correlation to observed temperature data. Applying the proposed water quality standards for temperature to the 2001 – 2007 CDOM data set does not suggest that attainment of these proposed standards is a good indicator of fish health.

While no definitive statement can be made about causation from regression analysis, the weak correlations between fish metrics and dissolved oxygen indicate that incremental improvements in water quality alone may have, at best, a small benefit to fish if all other conditions affecting fish in the system remain unchanged.

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4. ASSESSMENT OF HABITAT CONDITIONS IN THE CAWS

The physical habitat data used in this Study, described in Section 3, were evaluated to develop an understanding of conditions in the CAWS. This section provides a summary description of the physical conditions in the CAWS that are relevant to the physical habitat evaluation of the CAWS, based on observations and the data described in Section 3. This section consists of three main subsections:

- Section 4.1 discusses physical habitat conditions in the CAWS from the perspective of traditional physical habitat variables.
- Section 4.2 describes navigation in the CAWs as a functional component of the system, its impact on aquatic life in general, and its critical role in impacting aquatic biota and habitat in the CAWS.
- Section 4.3 contrasts habitat conditions in the CAWS with natural rivers.

4.1 SUMMARY OF PHYSICAL HABITAT CONDITIONS

The discussion generally follows the essential habitat assessment index components suggested by Rankin (1995) and described in Section 2-2, with some modifications for the CAWS, as described in Table 4-1. It should be noted that some of the habitat attributes described in Table 4-1, such as bank erosion and riffle-run/pool-glide sequences, are important to habitat assessment in natural systems, but they not important to developing a habitat index for the CAWS because they are nearly constant or are entirely absent.

Table 4-1: Comparison of Rankin Habitat Assessment Components to CAWS Habitat Description

Essential Habitat Assessment Component Identified by Rankin	Utility in CAWS Habitat Assessment
Substrate type and quantity	Important in CAWS, discussed in Section 4.1; physical aspects of substrate are important in the CAWS, but chemical aspects are also important
In-stream physical structure and cover	Important In CAWS, discussed In Section 4.2
Channel structure/stability/modification	Important in CAWS, discussed in Section 4.3 as Channel Morphology; stability is not important as most of the CAWS are constructed and channelized, designed and maintained for stability
Riparian width/quality	Riparian condition is important in the CAWS, discussed in Section 4.4; width not as important due to heavy riparian development in many parts of the system
Bank Erosion	Not prevalent in the CAWS because flows are low and the system is managed to maintain stable channels, mostly through bank armoring, therefore not a useful differentiator within the CAWS.
Flow/stream gradient	Hydrology is considered, discussed in Section 4.5; due to the heavily regulated nature of flows in the CAWS this is less important than in a natural system, therefore not a useful differentiator within the CAWS.
Riffle-run/pool-glide quality/characteristics	Completely absent from the CAWS, which consists mainly of canals and straightened channels, therefore not a useful differentiator within the CAWS.

The relevant aspects of physical habitat in the CAWS are discussed in the following sections.

4.1.1 Substrate Type and Quality

Bed condition, as measured by substrate type and quality, is a valuable component of aquatic habitat because of its role in providing cover and spawning habitat. Its importance to aquatic life and a discussion of substrate conditions in the CAWS are presented below.

4.1.1.a Importance of Substrate to Aquatic Life

Substrate is a relatively complex aspect of the aquatic environment, including both mineral and organic materials forming the bottom of a water body (Allan, 1995; Armantrout, 1998). It essentially includes everything on the bottom or sides or projecting into a body of water, including human artifacts and debris (Allan, 1995). Substrate is of critical importance both directly and indirectly to aquatic biota. The surface layer of substrate is often rich in organic matter and can provide an important source of nutrients for organisms at the base of the food chain (Gordon et al., 2004). It provides habitat for most species at some point in their life history for activities such as resting and movement, reproduction and refuge as well as direct and indirect food availability (Giller and Malmquist, 1998). Species differ in their substrate association and preference requirements and the distribution and composition of sediment is an important physical factor influencing the distribution of organisms within aquatic systems (Gordon et al., 2004).

Substrate can be a repository for chemicals introduced into aquatic systems as a result of agriculture, industry, and other human activity. Although not typically considered a physical habitat attribute in natural systems, anthropogenic contamination of sediments can have a significant impact on aquatic life. Contaminants of concern in aquatic sediments range from heavy metals to organic chemicals. Although these contaminants may only be found at low concentrations in water, they often accumulate at elevated levels in sediments (MacDonald and Ingersol, 2002).

Both the physical and chemical characteristics of substrate are important. Aquatic organisms can be exposed to contaminated sediments throughout their lifecycles and through multiple pathways. Benthic macroinvertebrates live in the sediments and are directly exposed to contaminants (USEPA, 2008), usually through ingestion or absorption. Larger species may consume the contaminated benthic organisms. This allows the contaminant to move through the food web and upper trophic levels (Burton and Landrum, 2003). Fish can be exposed directly to sediments during nesting or foraging or they may consume macroinvertebrates and smaller fish that have been previously exposed to contaminants. Additionally, resuspension of contaminated sediments in the water column can occur after disturbances such as storms or boat propellers (USEPA, 2008).

Depending on the contaminant, a series of negative effects may occur. Some contaminants, if present at sufficiently high concentrations, can result in acute toxicity, where toxic levels are reached with only one exposure. Aquatic life can also experience chronic toxicity after prolonged exposures. Because direct exposure of macroinvertebrates is more common than direct exposure of fish, changes in macroinvertebrate populations may be observed due to sediment contamination. Most obvious effects are seen in benthic community structure changes (Burton and Landrum, 2003; MacDonald and Ingersol, 2002). Deformities, lesion, and tumors in fish have been observed to have higher incidences in areas with contaminated sediments (USEPA, 2008).

4.1.1.b Summary Description of Bed Condition in the CAWS

Substrate in the CAWS is dominated by fine sediments. In the deep parts of sampling stations, usually near the center of the reach, inorganic silt was recorded as the dominant substrate type in 16 out of 28 sampling stations (Figure 4-1)[3]. Only five stations (three in the North Shore Channel, one on the Little Calumet River, and the

[3] The bar charts showing habitat variables in this section use colors to differentiate major reaches of the CAWS. The numbers at the bottom of the charts denote the sampling station identification numbers.

Harlem Avenue station of the CSSC) had sand as the dominant deep substrate, while two had organic sludge. The remaining five stations were found to be exposed to bedrock in the deep part of the reaches.

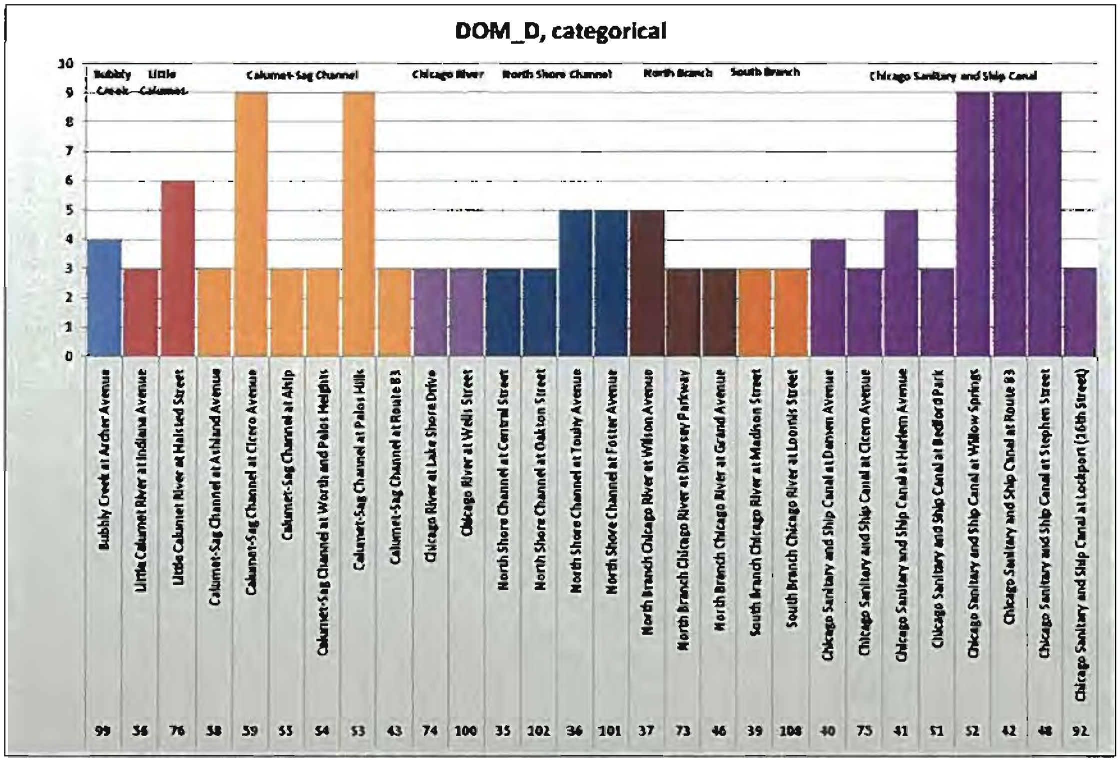

Figure 4-1: Dominant Deep Substrate (DOM_D) at CAWS Sampling Stations

(The y-axis corresponds to the variable: 1 = plant debris; 2 = clay; 3 = inorganic silt; 4 = organic sludge; 5 = sand; 6 = gravel; 7 = cobble; 8 = boulder; 9 = bedrock or hardpan; 10 = other)

Substrates in the shallower parts of the sampling reaches, nearer the sides of the channels, were slightly more varied but 14 sampling stations were found to be dominated by inorganic silts or organic sludge (Figure 4-2). Four stations had sand as the dominant shallow substrate, two had gravel, two had cobbles, and two had boulders. The remaining stations had bedrock or other hardpan beds. Where cobbles and boulders were encountered, they appeared to be remnants of failed riprap or stone walls that had collapsed into the channel.

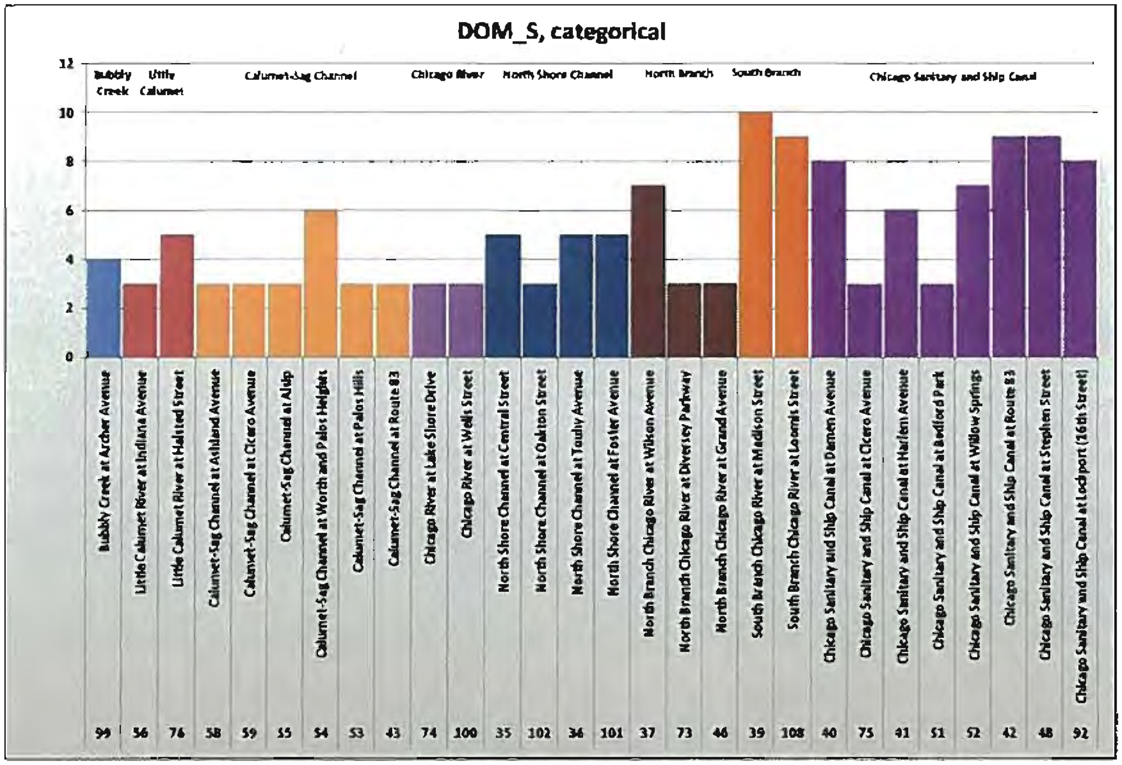

Figure 4-2: Dominant Shallow Substrate (DOM_S) at CAWS Sampling Stations

(The y-axis corresponds to the variable: 1 = plant debris; 2 = clay; 3 = inorganic silt; 4 = organic sludge; 5 = sand; 6 = gravel; 7 = cobble; 8 = boulder; 9 = bedrock or hardpan; 10 = other)

Sediment chemical data from the CAWS shows the presence of a wide range of chemicals throughout the system including pesticides, polychlorinated biphenyls (PCBs), and heavy metals. It was beyond the scope of this Study to comprehensively evaluate sediment chemistry in the CAWS, but the available sediment chemical data were compared to macroinvertebrate data collected from the CAWS. This comparison showed that many chemicals were significantly correlated with macroinvertebrate metrics ($p<0.05$) including the following:

- Several chemicals were inversely correlated with taxa richness in ponar samples including mercury ($r = -0.597$), cadmium ($r = -0.608$), chromium ($r = -0.548$), copper ($r = -0.565$), nickel ($r = -0.559$), lead ($r = -0.530$), zinc ($r = -0.524$), simultaneously extracted metals (SEM, $r = -0.630$), total PCBs ($r = -0.643$), and total semi-volatile organic compounds (SVOCs, $r = -0.548$).

- Cadmium ($r = -0.587$) and copper ($r = -0.530$) were correlated with Shannon diversity index in ponar samples.

- Cadmium ($r = -0.512$), SEM ($r = -0.565$), and total PCBs ($r = -0.570$) were correlated with Diptera richness in ponar samples.

- Several chemicals were positively correlated with the percentage of Oligochaeta in artificial substrate samples including cadmium ($r = 0.593$), chromium ($r = 0.560$), copper ($r = 0.580$), and nickel ($r = 0.618$).

- The percent of collector gatherers in artificial substrate samples was positively correlated with cadmium ($r = 0.509$), copper ($r = 0.572$), and nickel ($r = 0.528$).

- Functional feeding group diversity in ponar samples was inversely correlated with several chemicals including cadmium ($r = -0.589$), chromium ($r = -0.537$), copper ($r = -0.541$), nickel ($r = -0.527$), lead ($r = -0.535$), zinc ($r = -0.530$), simultaneously extracted metals (SEM, $r = -0.655$), total PCBs ($r = -0.624$), and total semi-volatile organic compounds (SVOCs, $r = -0.519$).

Data also show that mercury was significantly ($r = 0.659$; $p < 0.05$) correlated with head capsule deformities in macroinvertebrates collected using ponar samplers. These observations suggest that anthropogenic chemicals in CAWS sediments are affecting macroinvertebrate populations directly and suggest an indirect effect on fish as well. Based on these correlation analyses, three sediment chemical parameters were chosen for use in the habitat evaluation: cadmium concentration, total PCB concentration, and concentration of simultaneously extracted metals, which is a measure of the bioavailability of heavy metals in sediments.

4.1.1.c Sediment and Substrate Limitations in the CAWS

As described in Section 4.1.1, sediment and substrate is of critical importance both directly and indirectly to aquatic biota in natural systems. The sediment and substrate within the CAWS are generally dominated by exposed bedrock or fine materials. The fine materials include consolidated native soils into which some the channel were dug or fine sediment deposited in the system by urban runoff. The latter can be easily resuspended and redistributed. Table 4-2 describes some key habitat limitations in the CAWS, with respect to sediment and substrate, which likely limit the biotic potential of the fishery within the system.

Table 4-2: Habitat Limitations in the CAWS Related to Sediment and Substrate.

Sediment Feature	CAWS habitat and Fisheries Response
Suspended sediment	The CAWS is dominated by suspended sediments that result from a combination of urban surface runoff discharges, CSOs, treated discharges, and navigation resuspension. Sheehan and Rasmussen (1999) state that suspended solids have had a greater adverse influence on fish diversity and abundance in the Midwest than any other factor.
Sediment deposition	The channelized and flow regulated system has resulted in the settling and resuspension of fine sediments and subsequent deposition on surface materials. This has created a relatively homogenous condition that decreases habitat, favoring species adapted to a fine sediment environment (Wesche and Isaak, 1999).
Substrate Feature	**CAWS habitat and Fisheries Response**
Composition	Substrate in many parts of the CAWS consists of native hardpan or bedrock. The depositional environment created by the controlled flows has further resulted in surface layers within the systems that are dominated by fine sediments such as silt, clays and fine sands. Substrate is an important habitat feature for benthic organisms and those that rely on the benthos and the dominance of fine sediments across the system favors non-specialized omnivore species (Flotemersch et al., 2006; Rabeni and Jacobson, 1999).

Where large substrate (gravel, cobbles, boulders) are present in the CAWS, they appear to be important to fish. Future work in the CAWS should include collection of more data on large substrate and its importance to fish.

4.1.2 In-Stream and Overhanging Cover

Cover can be defined as structural material (e.g., boulders and woody debris), channel features (e.g. bank pockets, in-stream and overhead vegetation), water features (e.g., turbulence and depth), that provide protection for aquatic species from biotic and abiotic threats (Armantrout, 1998; Orth and White, 1999). It is an important aspect of physical habitat for aquatic fauna, particularly for fish.

4.1.2.a Importance of In-Stream and Overhanging Cover to Aquatic Life

The availability of cover is important for maintaining species and their various life stage components in inland waters. Cover significantly influences the composition, size, life stage and distribution of species within water bodies, although the community relationships are often complex (Bain and Stevenson, 1999). The most commonly used categories of cover include overhead bank cover, water depth, in-stream objects, and hydraulic features (Orth and White, 1999). Overhead cover includes stream bank and shoreline cover features such as riparian vegetation and woody debris which generally provide shallow water protective environments from predators and velocity as well as shading for thermal refuge. Deep waters can provide refuge for prey species from sight feeding fishes, thermal refuge during summer temperature peaks, and flow refuge for low velocity swimmers. In-stream cover includes course substrates, woody debris, emergent and submergent vegetation, and provides hiding cover, sources of food and reproductive features for a variety of species. Hydraulic features such as turbulent areas and off channel habitat can provide refuge from main channel velocities as well as serve as a source of protection from open water predators and reproductive protection from main channel flow dynamics.

4.1.2.b Summary Description of In-Stream and Overhanging Cover in the CAWS

Types of cover quantitatively evaluated in this Study include in-stream vegetation and overhanging riparian vegetation. As discussed in Section 3.1.2, in-stream submerged structure, other than macrophytes, was not measured in the CAWS because turbidity limited direct observation of submerged conditions. Side scan sonar was attempted and showed some promise, but the Study schedule did not allow for full characterization using this technology. In addition, qualitative notes on the presence and types of in-stream cover (woody debris, boulders, etc.) were available from District assessment forms. These observations were not quantified.

In-stream vegetation is limited in the CAWS; submerged aquatic macrophyte cover was non-existent at 19 of the 28 sampling stations surveyed in 2008. In fact, significant submerged aquatic macrophyte cover was only recorded in the North Shore Channel, four stations in the CSSC (Figure 4-3), the Little Calumet River, and one station in the Chicago River, near a marina. Emergent aquatic macrophytes were also measured by recording the number of different types in each station. These showed greater variety across the CAWS, but were not extensive in any areas and were limited to near-shore areas.

Percent overhanging canopy was also limited in the CAWS, although most reaches, with the exception of the Chicago River, had some overhanging canopy (Figure 4-4). Far more overhanging canopy was observed in the North Shore Channel than anywhere else and because this reach is the narrowest of the CAWS reaches, the percent of cover was much higher than any other reach.

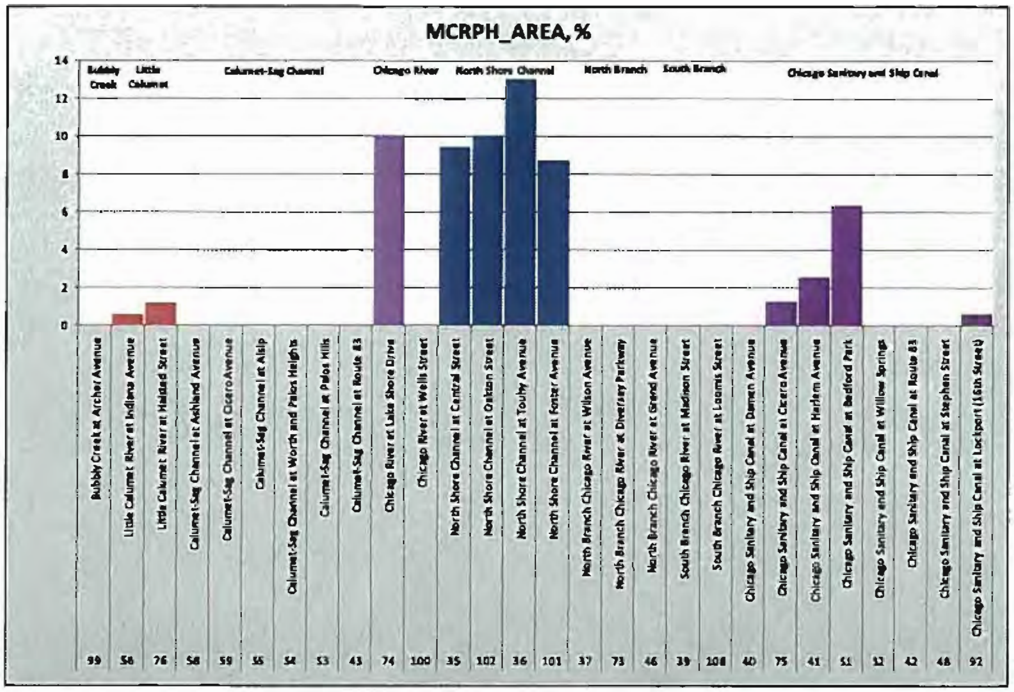

Figure 4-3: Submerged Aquatic Macrophyte Cover (%) in CAWS, 2008.

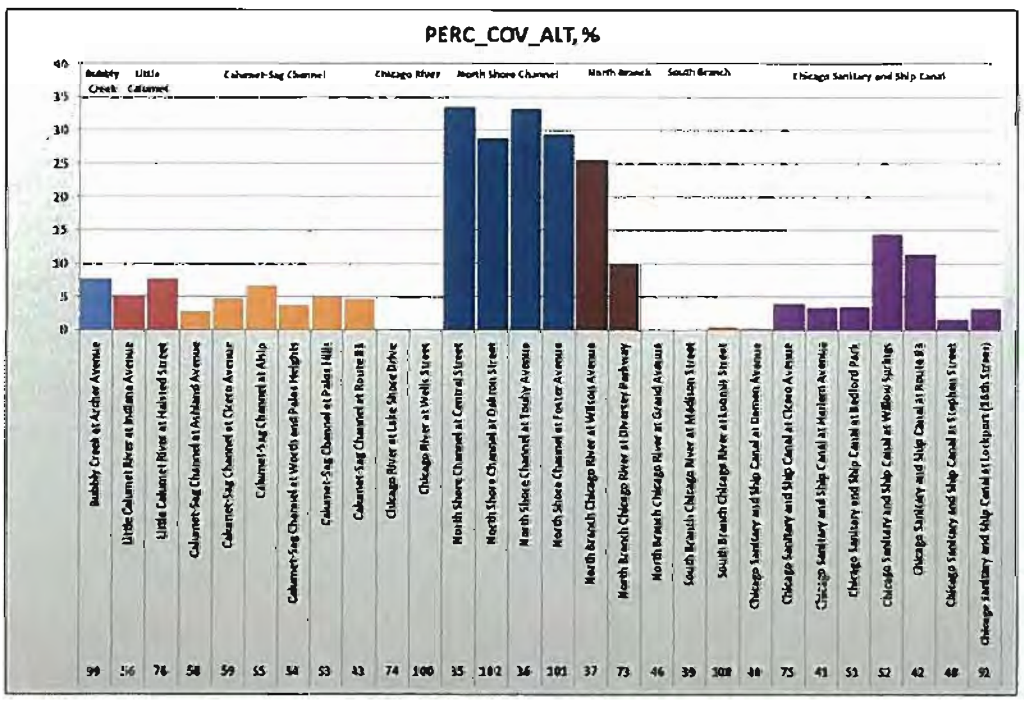

Figure 4-4: Overhanging Cover (%) in CAWS, 2008.

The limited in-stream and overhanging cover in the CAWS presents a challenge and an opportunity. The shortage of data poses a challenge for statistical analysis of physical habitat in the CAWS, but cover may be an attribute that can be improved in the CAWS.

4.1.2.c In-Stream and Overhanging Cover Limitations in the CAWS

In-stream and overhanging cover is important for maintaining species and their various life stage components in inland waters. As discussed in Section 4.2.1, cover significantly influences the composition, size, life stage and distribution of species within surface waters, although the community relationships are often complex (Bain and Stevenson, 1999). The design and maintenance of the CAWS for conveyance and navigation uses results in the management of the system for efficient flow transport and hazard free shipping traffic by removing obstructions of in-channel features. Table 4-3 describes some key habitat limitations in the CAWS with respect to cover.

Table 4-3: Habitat Limitations in the CAWS Related to In-Stream and Overhanging Cover.

In-stream Features	CAWS Habitat and Fisheries Response
Overhead cover	The available overhead cover within the CAWS is generally in the form of vegetation that has naturally developed along riparian areas. Some areas have large, well established portions of overhanging trees (e.g. North Shore Channel and the lower Cal-Sag). Generally, these features can provide shade from thermal inputs, habitat structure, and organic inputs for the fishery (Flotemersch et al., 2006).
In-stream vegetation	In-stream cover includes near-shore submerged and emergent aquatic vegetation that can provide essential littoral habitat. Within the CAWS, this form of in-stream cover is generally limited spatially because of the dominance of deep water (bank to bank) segments.
Water depth	Water depth is a direct result of the purposeful construction for either navigation (i.e., shallow draft or deep draft) or conveyance of effluent and flow controls within the system. The system is entirely non-wadeable. The depth, as a function of total volume, likely allows a dominance of fishes adapted to lentic water habitats and abundances greater than in rivers of greater channel diversity (Sheehan and Rasmussen, 1999).
In-stream structure	In-stream structure is limited in the CAWS. These features are generally considered obstructions to efficient flow conveyance or potential hazards to navigation traffic and are removed as part of channel maintenance procedures in large portions of the system. The absence of these in-channel features (e.g., root wads, snags, trees, etc.) likely affects the production potential for both macroinvertebrates and fish (Flotemersch et al., 2006) and results in a predominance of pelagic and transient species.
Hydraulic features	Some manmade features in the CAWS, such as SEPAs or pumped aeration stations may contribute to turbidity. Off channel habitats are rare and exist in the form of constructed dead-end canals (e.g., barge storage areas), areas within the few turning basins, and the limited number of fish passable tributaries within the system. The general lack of these features across the systems likely favors pelagic and transient species and limits refuge to support a more diverse fish community.

4.1.3 Channel Morphology

Channel morphology refers to the physical structure and shape of a waterway at a range of scales. In natural rivers, these qualities are referred to as fluvial geomorphology, but this term is not applicable in the CAWS because of its constructed and modified condition. Channel morphology in the CAWS differs dramatically from natural waterways. Neither the cross-sectional shape of CAWS channels nor their plan forms are similar to natural streams and rivers. This can have significant impacts on aquatic life, as discussed below.

4.1.3.a Importance of Channel Morphology to Aquatic Life

The importance of channel morphology to aquatic life has been recognized by ecological and fisheries professionals for decades (Edwards et al., 1984; Resh et al., 1988; Orth and White, 1999). Natural rivers and streams have sinuous plan forms that have evolved, and continue to evolve, through a balance of the sediment mobilization and transport capabilities of the flowing water and the geological materials that form their bed and banks. Straightening of natural channels reduces longitudinal and lateral variations in velocity within the channel, which reduces the variability of sediment erosion and deposition patterns. This variability is important as different aquatic fauna require variations in substrate for breeding, foraging, and refuge. As stated in Orth and White (1999):

> "Channelization creates unfavorable stream habitat…stream straightening results in loss of important fish habitat features associated with natural meandering and pool-riffle patterns…As a consequence, habitat diversity is reduced…Abundance of sport fish can be 8 – 10 times greater in natural channels than in channelized parts of the same stream."

Large sections of the CAWS were intentionally constructed with straight, uniform channels and other sections were intentionally straightened and dredged. In light of the above discussion, the relevance of this aspect of the CAWS with respect to fisheries is apparent.

4.1.3.b Summary Description of Channel Morphology in the CAWS

Channelization, involving straightening, widening, deepening, and armoring or walling of banks, is the major factor affecting channel morphology in the CAWS. In the CAWS, channels are very straight. The calculated sinuosity of the major CAWS reaches are summarized in Table 4-4.

Table 4-4: Summary of Reach Sinuosity in the CAWS

Reach	Length (mi)	Sinuosity
North Shore Channel	7.7	1.08
North Branch Chicago River	7.8	1.13
Chicago River	1.6	1.03
South Branch Chicago River	4.6	1.25
Bubbly Creek	1.5	1.06
Chicago Sanitary and Ship Canal	31.1	1.08
Cal-Sag Channel	16.1	1.02
Little Calumet River	6.0	1.29

To put these values in perspective, a perfectly straight channel has a sinuosity of 1.0. In natural rivers, sinuosity of 1.2 or less is considered low, whereas 1.5 or more is considered high (Rosgen, 1996). The lack of sinuosity in the CAWS is by design and not only has an impact on habitat, but has implications for selection of a habitat assessment protocol as discussed in Section 2.4.

At a smaller scale, channel cross-sectional geometry is another important aspect of channel morphology. Variations in depth along and across river channels are the natural result of the local soils, riparian condition, and system hydrology. These variations support the development of local habitat variations. In the CAWS, which consists of canals and modified channels, most reaches tend to be uniform and many reaches are dredged to maintain depth for navigation. The design and maintenance of the channels in the CAWS, along with the lack of a natural sediment load from the watershed, help to maintain channel uniformity. This is illustrated by the channel cross-sectional area measurements collected at the CAWS sampling stations for this Study, depicted graphically in Figure 4-5. This figure shows that, for most of the reaches, cross-sectional area is relatively uniform along the length of the channel. Notable exceptions are:

- On the Chicago River, the station at Lake Shore Drive has a significantly larger cross-sectional area than that at Wells Street because it is actually within the Chicago harbor area.
- The cross-sectional area at Loomis Street on the South Branch Chicago River is significantly larger than at Madison Street because the west end of the Loomis Street station includes a large slip.

- The Chicago Sanitary and Ship Canal at Lockport (16th Street) has significantly larger cross-section than other stations on the CSSC because this area is a wider part of the canal, used for staging barges.

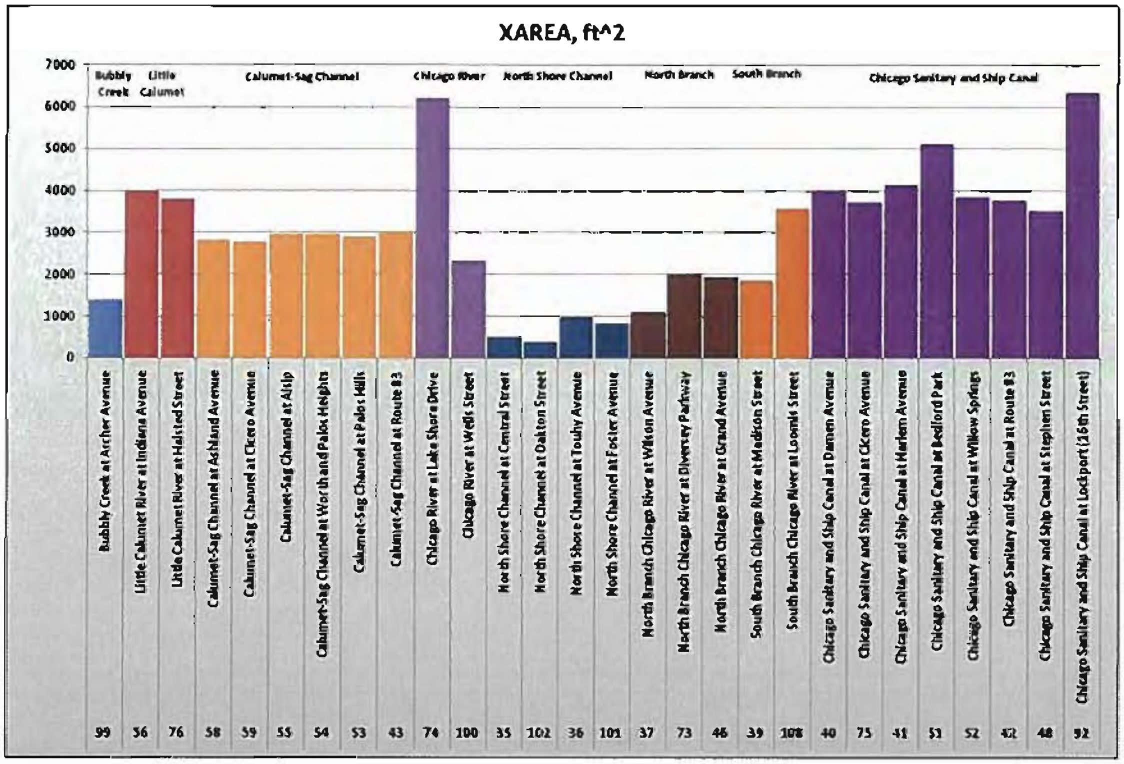

Figure 4-5: Channel Cross-Sectional Area at CAWS Sampling Stations

Aside from these exceptions, the data show fairly uniform cross-sections over long reaches. For example, the Cal-Sag Channel cross-section remains almost the same over approximately 16 miles of length.

The CAWS channels are also generally deep by design to support the primary functions of effluent conveyance, commercial navigation, and flood control. Figure 4-6 depicts the maximum channel depth at CAWS sampling stations used in this Study.

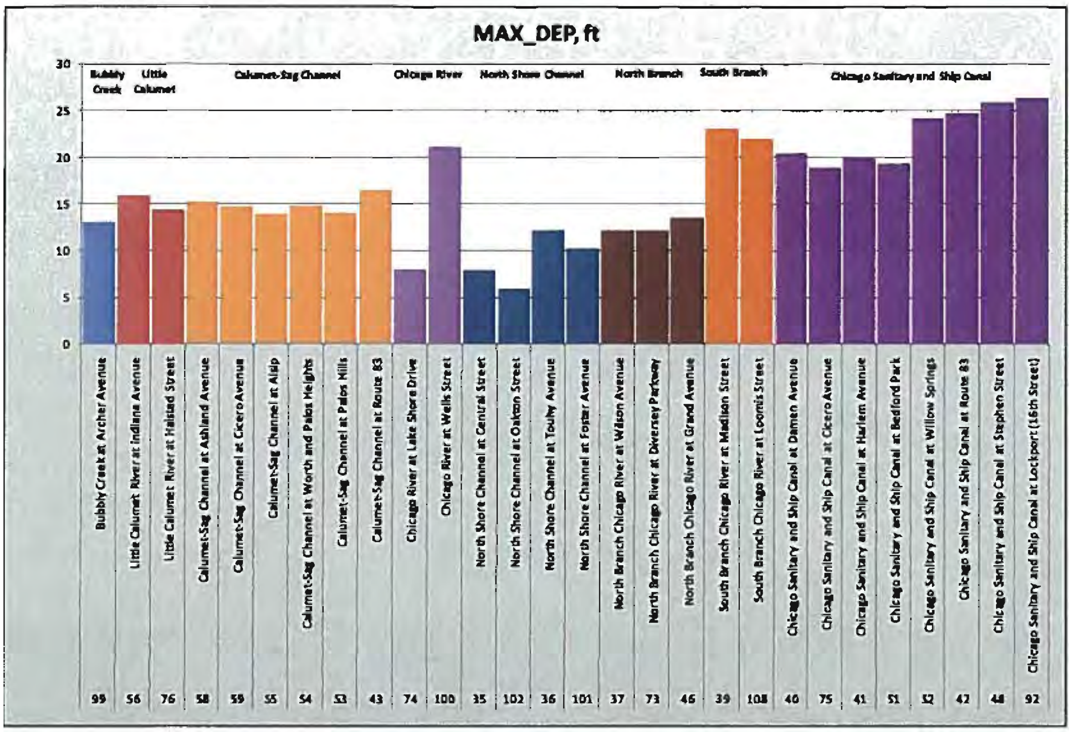

Figure 4-6: Maximum Channel Depth at CAWS Sampling Stations[4].

4.1.3.c Channel Morphology Limitations in the CAWS

Traditional geomorphology aims to understand landform features created by the dynamic processes of surface flowing waters (Gordon et al., 2004). Geomorphic features are used in biotic evaluations under the assumption that the physical characteristics help define the potential biotic characteristics (Gordon et al., 2004).

Within the CAWS, vague remnants of natural channels make up a relatively small component of the system, while the remainder of the system has been constructed through native soils and bedrock, where no channel existed previously. The plan and profile of the constructed channels in the CAWS offer relatively little variation compared to the characteristics offered in large, naturally formed, river systems. Some of the habitat limitations that these conditions impose are summarized in Table 4-5.

[4] It should be noted that the maximum depth at station 74 (Chicago River at Lake Shore Drive) represents the depth in the marina on the south side of the sampling station where, according to District personnel "most of the fish come from this area around the docks" (Minarik, 2009). Because the habitat data were compared to concurrent, collocated fish data in this study, it was important to characterize habitat at the location that best represented the fish sample. The actual maximum depth of the main channel of the Chicago River at this station is 23 feet.

Table 4-5: Habitat Limitations in the CAWS Related to Geomorphology.

Geomorphic Features[1]	CAWS Habitat and Fisheries Response
Entrenchment	Constructed channels make up most of the CAWS and no recognizable floodplain connection exists. Little or no off-channel refuge, developed littoral zone or shallow bank areas exist for various life stage needs of fish. Fishes adapted to lentic water habitats dominate (Sheehan and Rasmussen, 1999).
Width-Depth	Channels in the CAWS offer relatively little width-depth variation. Fishes adapted to lentic water habitats are dominant and their abundances are greater than in rivers of greater habitat diversity (Sheehan and Rasmussen, 1999).
Dominant channel materials	Fine sediment- and silt-dominated channel beds with intermittent reaches of bedrock are the most common bed condition. Resuspension from navigation maintains dominance of fine sediment surface materials. Limited channel material variation limits substrate uses to those species adapted to fine sediments and resuspension conditions.
Slope	Slope in the system is low and is managed and flow is controlled by the downstream control works at Lockport. System maintenance favors lentic species.
Bed features	Many of the CAWS channels are dredged for navigation and efficient conveyance and bed variation is limited. Limited features favor transient and open water species.
Sinuosity	Sinuosity generally removed from the system for the purpose of navigation passage and efficient conveyance. Limited features favor transient and open water species.
[1]Rosgen (Gordon et al., 2004).	

4.1.4 Hydrology

Hydrology is an important aspect of aquatic ecology in natural systems, but in highly regulated systems like the CAWS, its importance is less clear. This subject is discussed below.

4.1.4.a Importance of Hydrology to Aquatic Life

Flowing water serves many functions for aquatic biota including delivery of nutrients and food, and the removal of wastes (Allan, 1995). Faster flowing, more turbulent waterways are typically better aerated and contain higher levels of DO, essential for aquatic life. The velocity of flow in a channel is also important in determining sediment erosion and deposition. Channel modifications that cause significantly reduced velocities (such as impoundment by locks or dams) can result in increased deposition of fine sediments. Many aquatic organisms prefer either fast or slow moving water, but are less tolerant of experiencing both (Allan, 1995).

4.1.4.b Summary Description of Hydrology in the CAWS

The hydrology of the CAWS is not like that of a natural system. Hydrologic inputs to the system are nearly all regulated and affected by human activity. Figure 4-7 depicts the locations of the major controlling structures and sources of flow into the CAWS. Diversion of water from Lake Michigan into the CAWS is regulated by U.S. Supreme Court decree and by Federal regulations for the Chicago River (33 CFR 207.420, *Chicago River, Ill.; Sanitary District controlling works, and the use, administration, and navigation of the lock at the mouth of river, Chicago Harbor*) which state, in part, that:

> "The controlling works shall be so operated that the water level in the Chicago River will be maintained at a level lower than that of the lake, except in times of excessive storm run-off into the river or when the level of the lake is below minus 2 feet, Chicago City Datum."

Federal regulations also require control of the Calumet River (33 CFR 207.425, *Calumet River, Ill.; Thomas J. O'Brien Lock and Controlling Works and the use, administration and navigation of the lock*) which states, in part, that:

> "The controlling works shall be so operated that the water level at the downstream end of the lock will be maintained at a level lower than that of Lake Michigan, except in times of excessive storm run-off into the Illinois Waterway, or when the lake level is below minus 2 feet, Chicago City Datum."

The U.S. Army Corps of Engineers operates the locks referred to above, as well as the lock at Lockport, located at the southern end of the CAWS, which is the only hydrologic outlet from the system. These and other major hydrologic structures and sources on the CAWS are depicted in Figure 4-7.

Major flows into the CAWS include the Chicago River Controlling Works and the O'Brien Lock and Controlling Works, referenced above, as well as the Wilmette Pumping Station located at the northern end of the North Shore Channel, which pumps water from Lake Michigan into the North Shore Channel. Flows from the upper North Branch Chicago River are regulated by the North Branch Dam before entering the CAWS.

The District operates the Wilmette Pumping Station at the North end of the North Shore Channel, the sluice gates at the Chicago River Controlling Works, and the Lockport Powerhouse and Controlling Works at the south end of the Chicago Sanitary and Ship Canal. To manage storm flows and water levels in the CAWS, the District must lower the water level in the CAWS, sometimes by feet, in anticipation of significant storm events by reducing flow from Lake Michigan at Wilmette and the Chicago River Controlling Works and by diverting more water through the Lockport powerhouse.

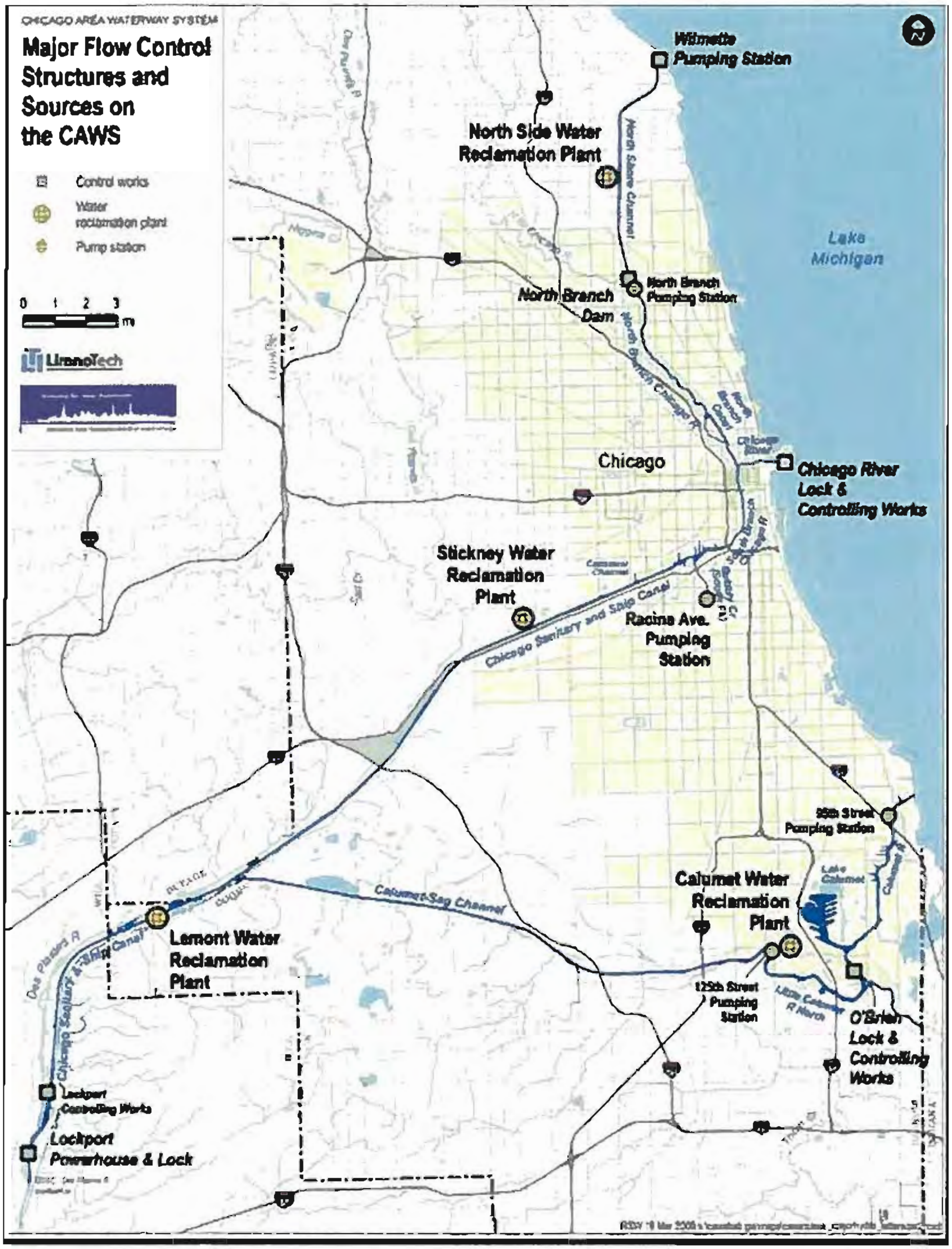

Figure 4-7: Major Hydrologic Structures and Flow Sources on the CAWS.

As shown in Figure 4-7, the District operates four water reclamation plants (WRPs) on the CAWS:

- The Northside WRP discharges to the North Shore Channel.
- The Stickney WRP discharges to the Chicago Sanitary and Ship Canal.
- The Lemont WRP discharges to the Chicago Sanitary and Ship Canal below the confluence with the Cal-Sag Channel.
- The Calumet WRP discharges to the Little Calumet River.

Together, these four WRPs discharge approximately 459 billion gallons of treated wastewater effluent to the CAWS annually[5]. A hydrologic balance using typical flow rates from various sources is summarized in Table 4-6. Review of these figures indicates that, on an annual average basis, 70% of the flow into the CAWS is effluent from these four WRPs. It is reported that during dry weather, mainly in winter months, approximately 100% of flow into the CAWS is WRP effluent and that in wet weather, mainly during summer months, WRP effluent accounts for approximately 50% of flow into the CAWS.

Flow is not measured in all reaches of the CAWS. In lieu of these data, flows and velocities calculated by a hydraulic model of the CAWS were used in this Study. This model, called DUFLOW, was developed by Dr. Charles Melching at Marquette University for simulation of water quality under unsteady flow conditions in the CAWS (Alp and Melching, 2008). The average flows and velocities predicted at the District's AWQM stations are depicted graphically in Figures 4-8 and 4-9, respectively.

[5] This total is based on reported average annual flows totaling 1,258 million gallons per day (District, 2008)

Table 4-6: Summary of Major Flows Into and Out of the CAWS

Flows Into CAWS	Flow (cfs)	Notes
Water Reclamation Plants		
North Side Water Reclamation Plant	377	1
Calumet Water Reclamation Plant	438	1
Lemont Water Reclamation Plant	4	1
Stickney Water Reclamation Plant	1,128	1
Wilmette Pumping Station	40.4	1
Locks and Controlling Works		
Chicago River Lock & Controlling Works	127.5	1
O'Brien Lock & Controlling Works	83.5	1
WPS Leakage	1.3	1
CRCW Navigation	27.4	1
CRCW Lockage	13.8	1
CRCW Leakage	14	1
OL&D Navigation	8.7	1
OL&D Lockage	19.1	1
OL&D Leakage	8.9	1
Pumping Stations		
North Branch PS	27.7	2
Racine Avenue PS	59.7	2
95th Street PS	-	5
122nd Street PS	-	5
125th Street PS	10.9	2
Tributaries		
Grand Calumet River	14	6
North Branch Chicago River at Albany Avenue	246	6
Little Calumet River	195	7
Tinley Creek	17.8	6
Midlothian Creek	18.7	6
Mill Creek + Stoney Creek (W)	30.7	8
Narajo Creek + Calumet-Sag Basin	7.2	8
Stoney Creek (E)	21.9	8
Calumet-Sag End Watershed	18.6	8
Lower Des Plaines basin	13.2	8
Calumet Union Ditch	21.9	8
Total Average Flow Into CAWS	**3,000**	
Flows Out of CAWS	**Flow (cfs)**	**Notes**
Lockport Controlling Works (LCW) /Lockport Powerhouse & Lock (LPL)	2582	4
Total Average Flow Out of CAWS	**2582**	

1. Reported as average annual flow for calendar year 2006 (District, 2008)
2. Data reported as average daily flows from July 12 to November 9, 2001 (Alp and Melching, 2008)
3. Average annual flow for 2005, measured by USGS at Romeoville Road (District, 2008).
4. Average annual flow for calendar year 2005, measured by USGS at Romeoville Road (USGS).
5. Unknown.
6. River Data reported as average daily flows from July 12 to November 9, 2001 (Alp and Melching, 2008)
7. Average discharge at USGS gage at South Holland, 2001 – 2008.
8. River Data marked as estimated flows and reported as average daily flows from July 12 to November 9, 2001 (Alp and Melching, 2008)

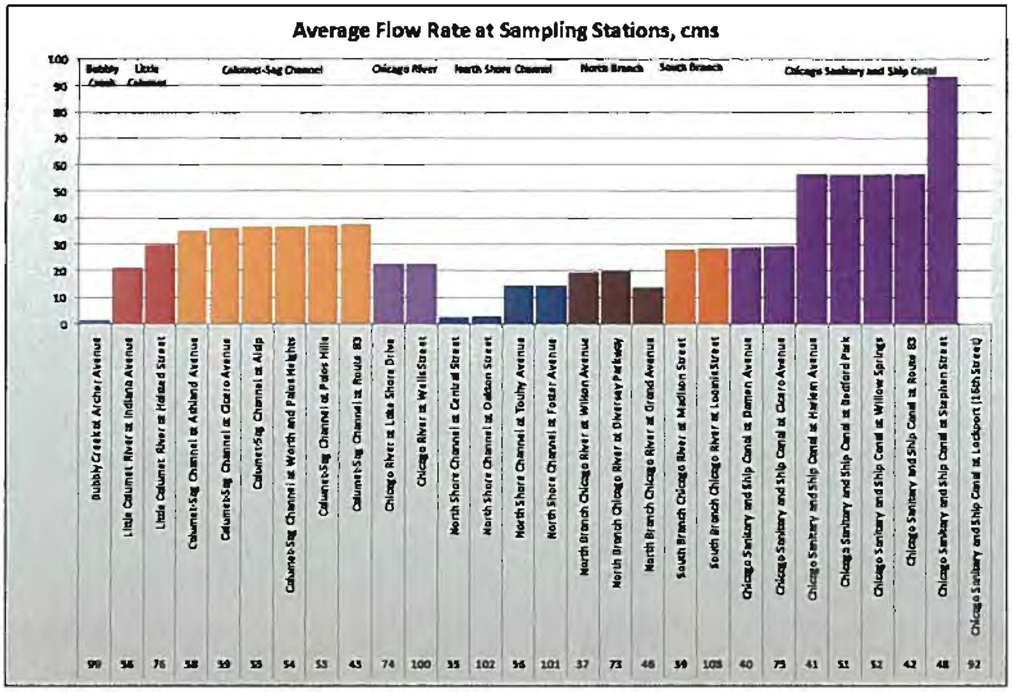

Figure 4-8: Average Flow Rate at CAWS Sampling Stations.

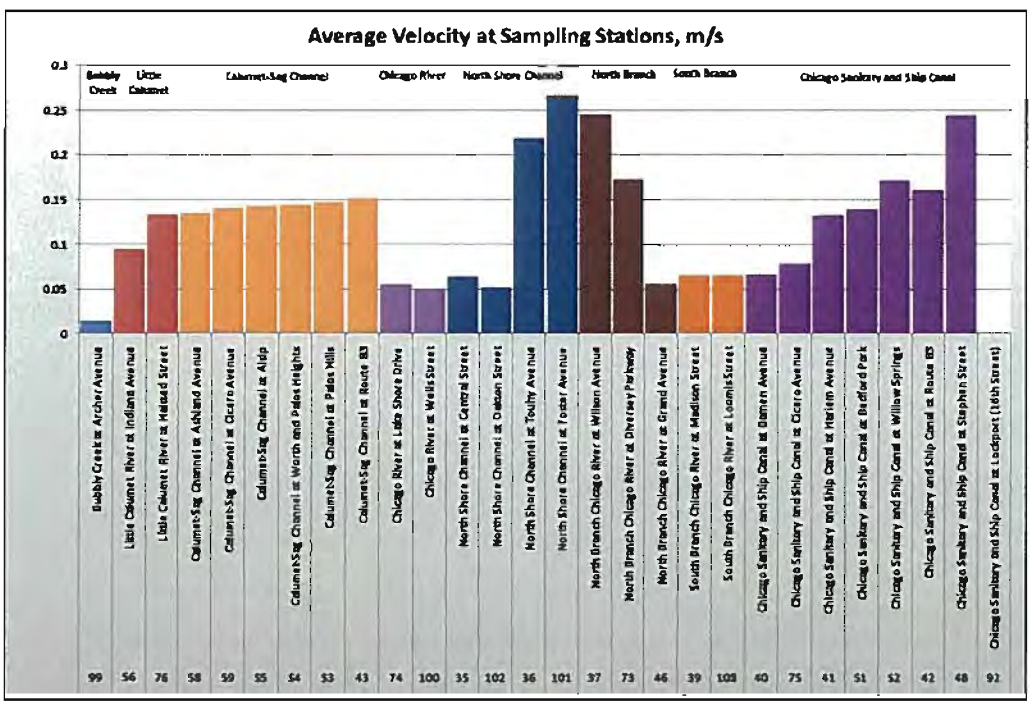

Figure 4-9: Average Velocity at CAWS Sampling Stations.

The DUFLOW model indicates that many parts of the CAWS experience very low flows, particularly Bubbly Creek and the North Shore Channel. Flow conditions in Bubbly Creek are typically stagnant; flow only occurs when the Racine Avenue Pumping Station discharges combined sewer overflow. The North Shore Channel upstream of the North Side WRP typically experiences little flow. Exceptions occur during wet weather events, when flow from the 11 large gravity CSO outfalls upstream from the North Side WRP exceed the dry weather flows in the North Shore Channel.

The CAWS was specifically designed to convey effluent and provide navigation passage and requires hydraulic controls both upstream and downstream to meet its designed uses. These controls have been described previously and have resulted in a system that functions similar to a reservoir. The CAWS is modeled to have a hydraulic residence period of over 8 days, although this varies depending on wet weather management needs for the system. The constructed nature of the CAWS and the operation of the flows within the system are likely adversely influencing the composition and distribution potential of the biota within the system. Orth and White (1999) describe that artificial flow manipulations in systems are well documented to adversely affect fishes, although the specific effects on the biota within the CAWS remain unknown. Hayes et al. (1998) suggests that reservoir systems contain a relatively simple trophic structure that is particularly vulnerable to the flow operation of the systems. This is significant because of the reservoir-like operation of the CAWS.

4.1.4.c Hydrology Limitations in the CAWS

Hydrology is regarded as a key driver of river and floodplain ecosystems and has been called the "master variable" of aquatic integrity (Gordon et al., 2004). In natural systems, the flow regime affects the structure and function of in-stream habitats as well as biotic factors such as distribution, abundance and competition (Flotemersch et al., 2006). As discussed in Section 4.5, the CAWS functions entirely under a regulated and managed system of controls for the purpose of conveyance and navigation stage maintenance. The hydraulic residence time in the CAWS (> 8 days) suggests that the system may function more like a lake or reservoir than a river system and its biota may be responding as such. Table 4-7 describes habitat limitations in the CAWS related to hydrology.

Table 4-7: Habitat Limitations in the CAWS Related to Hydrology (after Bunn and Arthington, 2002)

Hydrology Feature	CAWS habitat and Fisheries Response
Flow	Flow is regulated within the CAWS for navigation, effluent conveyance and stormwater management. Bunn and Arthington (2002) cite flow as the major determinant of physical habitat and biotic composition in river ecosystems. The artificial nature of the physical habitat and regulation of flow suggests that the CAWS biota would be unlike that of systems formed by under the influence of flow. Further, flow associated with the navigation lockage allows intermittent passage of fishes, while the downstream portion of the system contains an electric barrier that prevents upstream or downstream passage past the barrier.
Flow regime	As described previously, the flow is regulated within the CAWS. The resemblance of a natural flow regime within the system has also been removed. Bunn and Arthington (2002) state that species whose life history strategies have evolved with defined flow regimes may experience recruitment failure in managed systems. These altered systems promote the establishment, spread and persistence of exotic and introduced species (Bunn and Arthington, 2002).
Longitudinal and lateral connectivity	The CAWS is maintained within a narrow stage range for specific uses. Deep channels are maintained across the system. Laterally varied habitats are rare due to the constructed nature of the system. The limited lateral connectivity may lead to recruitment failure (Bunn and Arthington, 2002) or a general decrease in the abundance and diversity of juvenile fishes (Wesche and Isaak, 1999).

4.1.5 Bank & Riparian Conditions

Bank and riparian conditions are important in any system, but become particularly important in urban waterways where extreme modification of banks can occur and where urban land uses typically impinge closely on waterways to provide access to the water or simply to maximize available land area.

4.1.5.a Importance of Bank and Riparian Conditions to Aquatic Life

As the transitional zone between a watercourse and the surrounding land, bank and riparian areas have a direct effect on aquatic life. The shape and material of banks affects the ability of aquatic organisms to utilize the bank for cover and spawning. A vertical walled channel will offer very different physical habitat from a natural sloped bank. Materials such as rip-rap can offer a habitat for warm water fishes that is often beneficial (Fischenich, 2003). Banks which lack cover expose eggs and nests to higher flow velocities and wave-induced turbulence. Riparian vegetation can moderate water temperature by shading and slowing heat loss (Kohler and Hubert, 1999). Vegetation also reduces nonpoint source pollution by filtering overland flow and reducing sediment and nutrient loads. In natural systems, riparian vegetation provides bank stabilization and leaf litter energy inputs (Kohler and Hubert, 1999).

Riparian land use affects the volume and composition of water entering a watercourse. Activities on adjacent land can disturb biota through direct runoff of sediment and contaminants. Proper characterization of aquatic habitat involves consideration of bank and riparian condition.

4.1.5.b Summary Description of Bank and Riparian Condition in the CAWS

About seventy-five percent of the CAWS waterways are manmade and located where no previous waterway existed. Long stretches of banks consist of near-vertical walls designed to prevent erosion and to provide access for commercial and industrial activities. These urban channels provide efficient stormwater conveyance and flood control.

Bank and riparian conditions vary widely in the CAWS. The North Shore Channel has more riparian vegetation than most of the CAWS, with open space being a common riparian land use. Along the North Shore Channel, banks have a natural appearance, with little structural reinforcement. In waterways nearer to downtown Chicago such as the Chicago River, the North and South Branches, and the South Fork, commercial and industrial land uses dominate and riparian vegetation is largely absent. Banks are typically walled concrete or steel, offering little shelter for aquatic life. The Chicago Sanitary and Ship Canal has interspersed riparian vegetation and riparian land use changes from industrial in the east to more open space toward the west.

The banks are a mix of bedrock, steel sheet piling and more natural-looking banks. The Little Calumet River and the Calumet-Sag Channel have more riparian vegetation than the CSSC, with open space being common due to the Palos-Sag Forest Preserves (CDM, 2007). Like the CSSC, the banks are a mix of stone blocks, steel sheet piling and earthen banks with vegetation. Riprap banks are common throughout the CAWS. Table 4-8 summarizes the lengths of riprap and vertical-walled banks (including bedrock, stone block, steel sheet pile, wooden bulkhead, and concrete) in the CAWS, by reach. These measurements were obtained through visual inspection of the entire CAWS, using the digital video survey collected for this study.

As shown in Table 4-8, nearly 95 miles of the approximately 156 miles of banks in the CAWS (61%) are riprap or vertical walls, imposing potentially significant limitations on aquatic habitat. Bank revetments, intended to stabilize bank and prevent erosion, can impact aquatic life by disconnecting the channel from the riparian zone and limiting shallow littoral zones. Shallow bank areas that can provide refuge for fish are virtually eliminated.

Table 4-8: Bank Modification in the CAWS, by Reach

Reach	Total Length of Riprap Banks (mi)	Total Length of Vertical Walled Banks (mi)
North Shore Channel	1.1	0.4
North Branch Chicago River	5.2	8.0
North Branch Canal	0.5	1.5
Chicago River	0.0	3.1
South Branch Chicago River	0.4	8.0
Bubbly Creek	0.1	1.3
Chicago Sanitary and Ship Canal	3.3	35.5
Cal-Sag Channel	17.2	6.1
Little Calumet River	2.2	0.6
Total	**30**	**64.5**

Riparian vegetation is common in some parts of the CAWS, particularly in the North Shore Channel and parts of the CSSC and Cal-Sag (Figure 4-10). Riparian vegetation was not catalogued in detail, but ranges from low shrubs to larger overhanging trees. It should be noted that, because of extensive bank modifications in much of the CAWS, the presence of riparian vegetation has limited impact on aquatic habitat. The vertical walls or riprap embankments act as a physical separation between the aquatic environment and the riparian environment in many cases. Where riparian vegetation overhangs the water, there is a benefit from partial shading and deposition of organic material, but the benefit is not as full as it would be in the absence of this physical separation.

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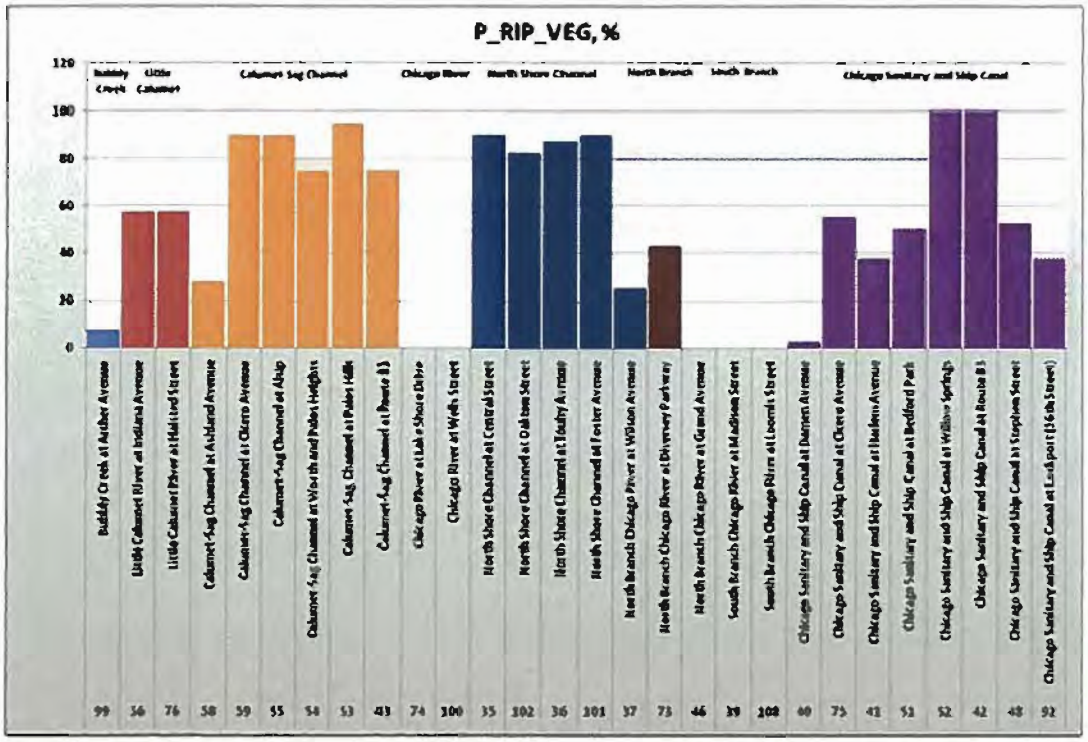

Figure 4-10: Percent Riparian Vegetation at CAWS Sampling Stations.

Another important aspect of bank condition in the CAWS is the presence of small and large areas that can provide fish refuge. Small areas of refuge in the banks were measured in this Study and are prevalent, as shown in Figure 4-11. These bank pocket areas were defined as small protection areas (greater than 1 square meter), visible to field crews, that may serve as refuge.

In addition to small pocket in the banks, there are some larger areas of refuge in certain parts of the CAWS. These were quantified and the results are depicted graphically in Figure 4-12.

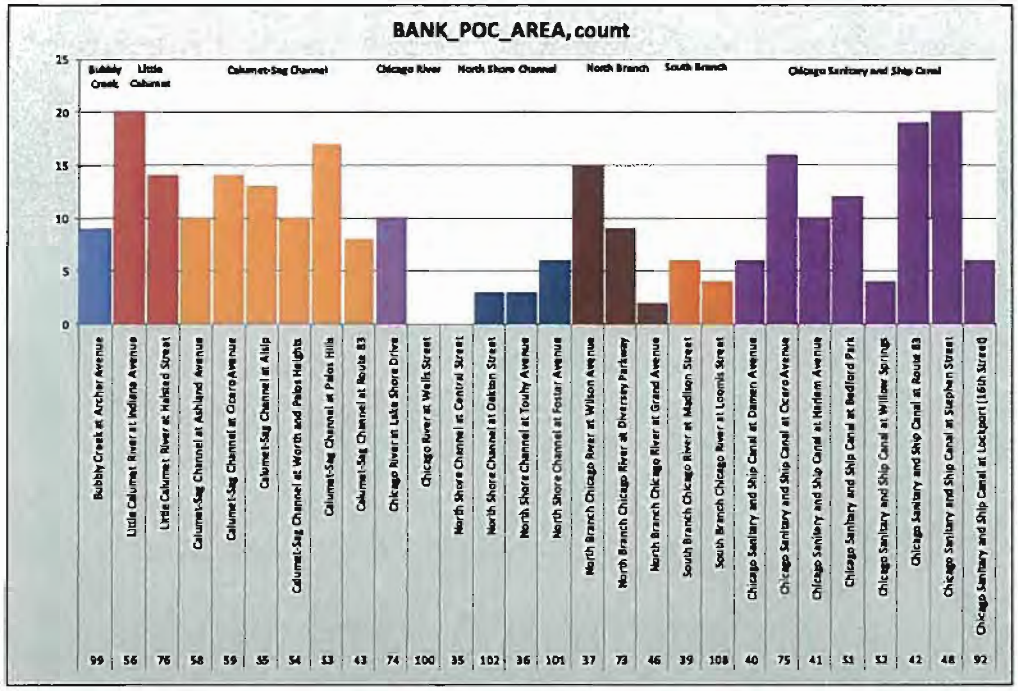

Figure 4-11: Bank Pocket Areas in CAWS Sampling Reaches.

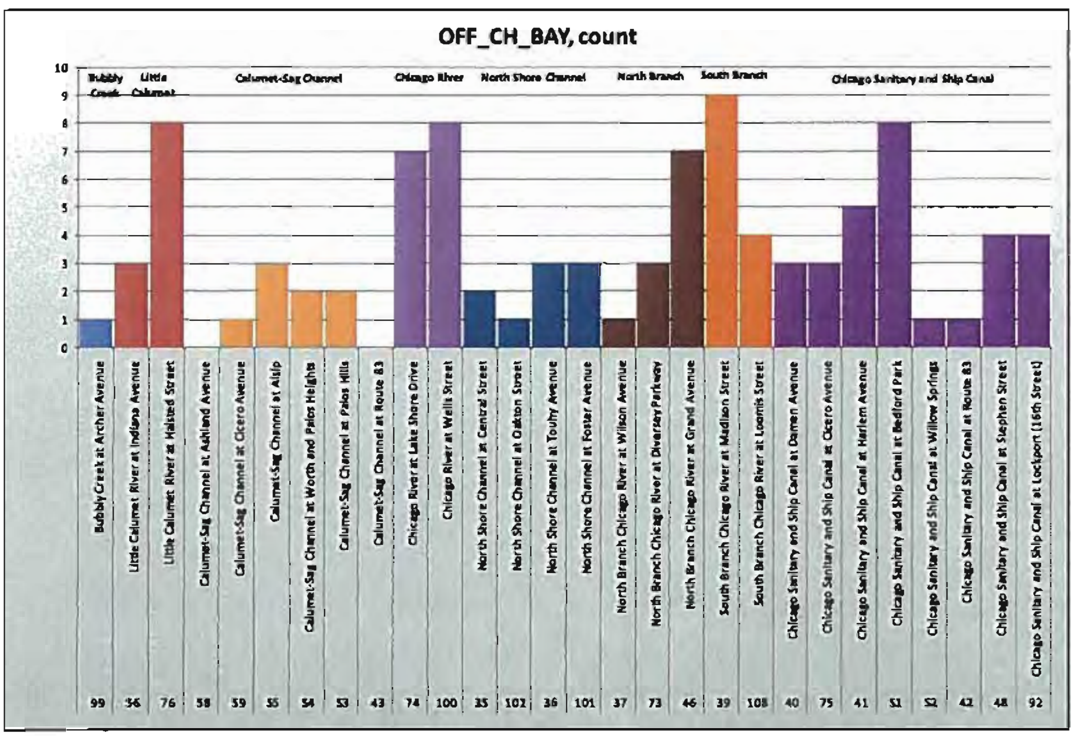

Figure 4-12: "Off-Channel Bays" in CAWS Sampling Reaches.

4.1.5.c Bank and Riparian Condition Limitations in the CAWS

Bank and riparian areas have a direct effect on aquatic life, as the shape and material of banks affects the ability of aquatic organisms to utilize the bank for cover and spawning. In addition, activities on riparian land can disturb biota through direct runoff of sediment and contaminants. Most of the entire length of the CAWS has modified or constructed banks and/or urban riparian conditions. These conditions range from long segments of sheet-piled, industrial loading facilities to natural banked reaches with dense riparian vegetation. Table 4-9 describes some bank and riparian condition limitations in the CAWS.

Table 4-9: Habitat Limitations in the CAWS Related to Bank and Riparian Condition

Bank and Riparian Features	CAWS Habitat and Fisheries Response
Riparian Land Use	Riparian land use within the CAWS includes a mix of uses from protected forest preserves in the lower Cal-Sag, to heavy industrial uses on the CSSC. The constructed and urban developed nature of the CAWS has created a unique system where typical watershed runoff conditions do not apply. Surface flows across the system do not generally drain towards channels because the channels were constructed where none existed previously. Slopes towards the channels exist only immediately adjacent to the channel, and tend to be flat or even sloping away from the channel outside the channel. Thus, within the CAWS, riparian land use effects are generally limited to immediately adjacent to the channel. Numerous authors have linked riparian alteration to degraded aquatic conditions (Flotemersch et al., 2006), and the effect on the fisheries are likely similar to those described previously for the overhead bank cover.
Bank Angle	Bank angle within the CAWS is a direct result of the construction. Much of the system (over 60 percent) has some form of armored banks and much of that portion has reinforced vertical walls. Bank angle within typical rivers is a descriptor of stability under various flow regimes and watershed influences, and a dominance of steepened banks are common in modified systems. These modified shorelines are commonly associated with poor fish habitats (Flotemersch et al., 2006). Within the CAWS, bank angle tends to be similar above the water line as below, so a vertical wall above the waterline typically describes a deep shore condition. Bank angles of less than 90 degrees suggest some form of littoral zone that may be used by fishes for feeding or refuge.
Bank Type (Material)	Bank types within the CAWS tend to consist of vertical walls (e.g., wood, sheet pile, concrete, stone block), boulder rip-rap, or natural vegetated banks. Much of the system has reinforced banks (i.e., walls or rip-rap) while the remainder consists of earthen constructed banks. Modified banks and shorelines are commonly associated with poor fish habitats (Flotemersch et al., 2006). The vegetated banks tend to be occupied by trees or large shrubs that serve a similar purpose to fishes as overhanging bank cover.
Riparian Vegetation	Riparian vegetation within the CAWS, where present, consists of mature stands of trees and shrubs adjacent to the channel up to several meters away from the channel. Much of the benefit to the CAWS channels come from the vegetation immediately adjacent to the channel because the channels do not have naturally sloping banks. The riparian vegetation, where present, serves a similar purpose to fishes as overhanging bank cover although in natural systems the extent, connectivity and quality of riparian vegetation is often linked to ecological condition (Flotemersch et al., 2006).

4.2 NAVIGATION IMPACTS IN THE CAWS

A majority of the CAWS was constructed, where no channel previously existed and is managed specifically for urban uses such as treated effluent conveyance, but much of the system was also designed to support commercial navigation. Navigation is not a true physical habitat attribute, but it represents a functional attribute of the system that has direct and indirect relevance to fish and their habitat. Any evaluation of habitat in the CAWS would be incomplete without consideration of navigation through the system. The impact of navigation on aquatic biota and habitat in the CAWS is discussed below.

4.2.1 Summary Description of Navigation in the CAWS

The Chicago Sanitary and Ship Canal, the Cal-Sag Channel, the South Branch Chicago River, Chicago River, and the Little Calumet River are all used for commercial navigation. No new measurements of navigation traffic were collected in this Study, but as described in Section 3.3.5, 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 were obtained to better understand commercial navigation patterns in the CAWS. These data were reported in terms of commodity tonnages (Figure 4-13) and the data used covered the period of 2001 through 2004.

As expected, the Chicago Sanitary and Ship Canal, the Cal-Sag Channel, and the Little Calumet River are the most heavily used reaches for commercial navigation, with each passing more than 25 million tons of commercial cargo between 2001 and 2004. In the same period, the South Branch Chicago River passed a little more than 5 million tons and the Chicago River passed less than 1 million tons. As stated earlier in this report, data on detailed movements within these reaches are not available (Brammeier et al., 2008). However the data verify the heavy usage of certain reaches for commercial navigation and allow for characterization of the reaches, compared to reaches that experience relatively light recreational navigation. A map showing the distribution of commercial navigation traffic in the CAWS is shown in Figure 4-14.

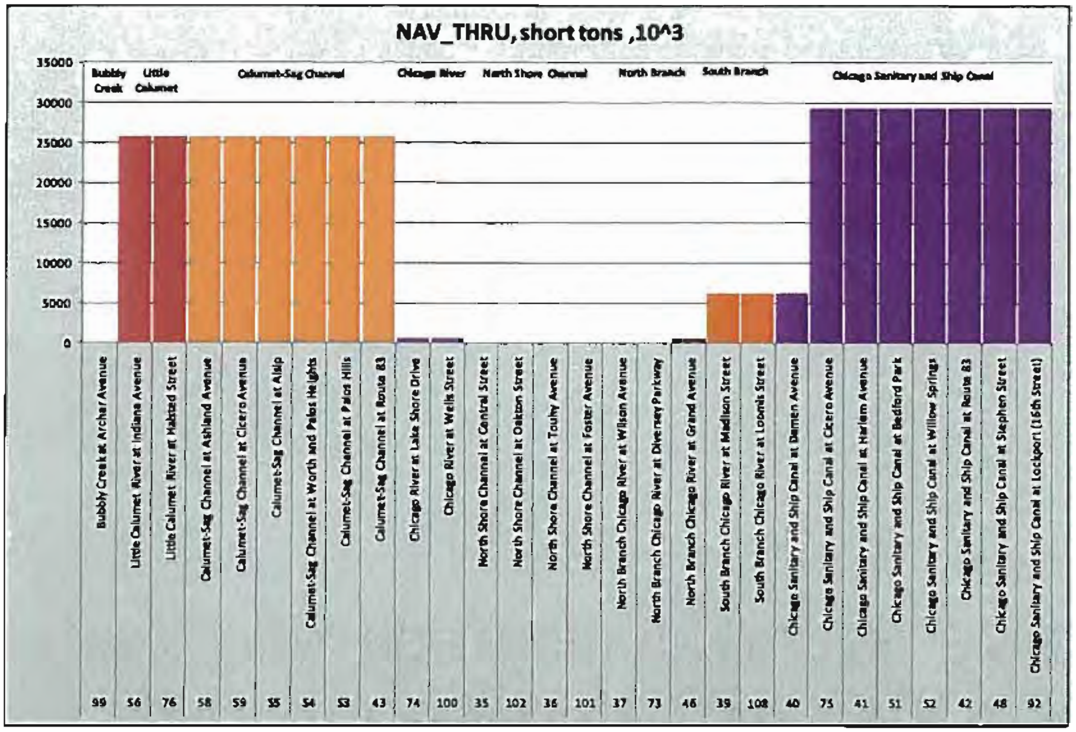

Figure 4-13: Commercial Navigation Through the CAWS, as Indicated by Tonnage.

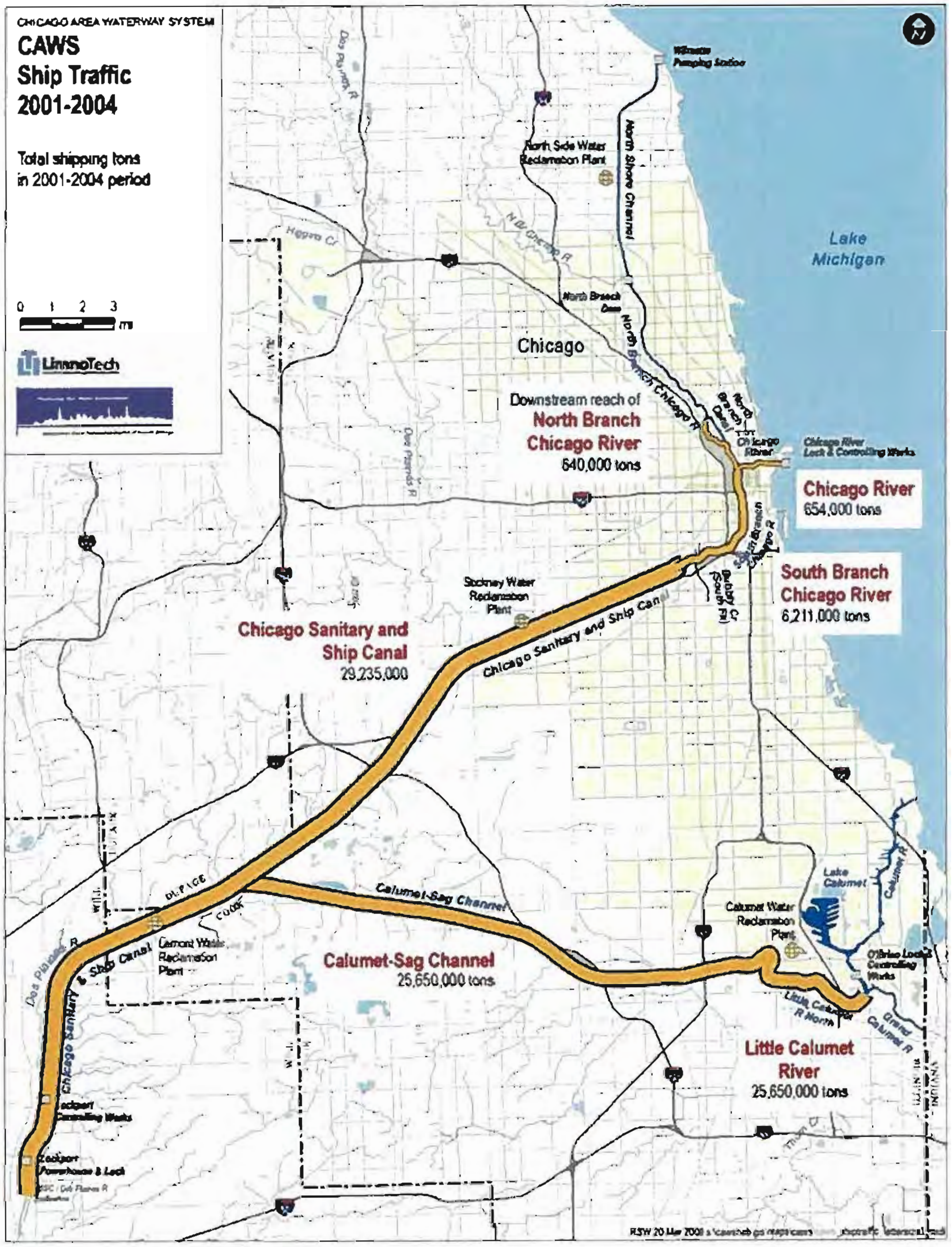

Figure 4-14: Commercial Navigation Through the CAWS.

4.2.2 Impacts of Navigation to Aquatic Life

The impacts of navigation on aquatic habitat and biota are numerous and well-documented in the scientific literature. These impacts are summarized below:

4.2.2.a Channel Modification for Navigation

Wolter and Arlinghaus (2003) provide a summary of the multi-use nature of navigation systems, describing the additive impacts resulting from straightened channels, dredging, shoreline stabilization and flow regulation. These authors also state that the cause and effect relationship is always similar: habitat fragmentation, habitat simplification, habitat loss (especially spawning and nursery habitats for migratory species), and the adverse hydraulic forces that directly affect aquatic species. Channel modification to support navigation has the following impacts:

- Straightening – Straighter channels are more efficient for navigation because they are easier to navigate and provide a shorter distance between points. Straightened navigation channels lack sinuosity and have less flow variability.
- Deepening – Commercial navigation vessels have deeper drafts than non-commercial vessels, requiring deeper channels. Dredging provides that depth and deepening often includes deepening from bank to bank, particularly in areas where barges and other vessels must dock. This results in lack of depth variability and loss of shallow areas which many species require.
- Bank modification – Wakes from vessels can cause bank erosion and traditional methods of erosion prevention include hard revetments such as riprap or sheet piling. Vertical sheet piling and bulkheads are also used for bank protection in docking areas. These modifications effectively disconnect the water from riparian areas and further reduce shallow water areas.
- Floodplain disconnection – Channelization (the combination of the three factors above) often result in disconnection of the floodplain from the channel.
- Substrate removal – Navigation channels, like the CAWS, require maintenance dredging which removes substrate and completely disrupts the benthic zone. This has a direct negative impact on benthic biota.
- Hydrologic regulation - Lock and dam structures are often required to control water levels, as is the case on the CAWS. Historically, the engineering of rivers to meet these requirements has lead to waterways which lack natural or diverse habitat. Research has shown that there is a clear relationship between the lack of habitat and aquatic life assemblages in navigable waterways (Wolter, 2001; Wolter and Arlinghaus, 2003). The controlling of water levels can also lead to the loss of spawning areas and negatively affect stock recruitment (Barlaup et al., 2008, Schramm et al., 2008). Sheehan and

Rasmussen (1999) suggest that the lock and dam systems developed and operated for navigation creates a lentic environment favoring lentic aquatic species.

All of these impacts are apparent in the CAWS. The CAWS consists mostly (about 75%) of manmade waterways that were designed to be straight and deep, where no floodplain originally existed and where the substrate is largely the native earth into which the channels were first dug. The rest has been modified and much of it exhibits the characteristics described above. These characteristics impose severe limitations on aquatic habitat and the biota that depend on it.

4.2.2.b Direct Impacts on Fish

In addition to the effects resulting from channel modification described above, navigation traffic also directly impacts aquatic life. As a ship travels through restricted waterways a series of forces are exerted including propeller wash, bank-directed current, return current opposite to the direction of the moving vessel, and drawdown (Wolter et al., 2004). These forces cause negative effects which can be divided into direct and indirect categories. Direct effects of navigation are a result of physical forces on aquatic life caused by moving vessels (Wolter and Arlinghaus, 2003). Indirect effects are associated with vessel induced disturbances which prevent normal aquatic life behaviors (Wolter and Arlinghaus, 2003). Many different levels of aquatic biota are negatively affected by these forces.

- Propeller impacts – The most direct way that navigation can affect fish is by propeller impact. Moving ship propellers can injure or kill fish by direct impact, but injuries to fish in proximity to propellers can also occur due to shear stress or pressure changes (Gutreuter et al., 2003).

- Increased shear stress – Moving vessels create moving water, which can increase shear stress on substrate, banks, and organisms themselves. It has been documented that navigation in channelized waterways can kill fish eggs and larvae by causing rotation or deformation (Morgan et al., 1976).

- Increased velocities – In addition to shear stress, water velocities caused by navigation may be too fast for small juvenile fish and force washing out, injury, or displacement (Wolter et al., 2004; Arlinghaus et al., 2002).

- Dewatering – Dewatering can also cause direct effects on aquatic life. Passing vessels displace water which is pushed to the sides of the channel, resulting in temporarily increased water levels, but in the wake of the vessel's passage, the water quickly moves back into the channel and can dewater nearshore sediments due to temporary water level drawdown. Drawdown forces at intervals associated with navigation traffic have been shown to significantly increase mortality for walleye and northern pike eggs (Holland, 1987).

- Wake impacts – Indirect impacts of navigation on aquatic life, although not immediately lethal, can pose a serious threat to certain species. As ships move through restricted waterways, their waves can disturb benthic invertebrate assemblages colonizing littoral zones and force detachment from bottom substrates (Gabel et al., 2008).

- Noise – Navigation traffic also results in noise of high amplitude and frequency. This noise has been shown to increase the levels of cortisol secretion and indicate elevated levels of stress in fish (Wysocki et al., 2006). Heavy boat traffic has also been shown to decrease the food conversion efficiency of fish when compared to similar species from other habitats (Penczak et al., 2002).

- Suspended sediment – As described above, passing vessels can increase shear stress on substrate, causing resuspension of unconsolidated fine sediments. This increase turbidity in the water column which can have harmful effects on fish gills and, particularly in urban waterways like the CAWS, it can introduce potentially toxic anthropogenic chemicals from the sediments to the water column. The repeated suspension and redepositon of fine sediments from vessel passage can spread sediment-bound contaminants and clog coarser substrate materials.

Although there are insufficient data at present to quantify these effects on biota specifically in the CAWS, the impacts almost certainly are occurring and cannot be ignored. Further research would be required to document and quantify navigation-related impacts to aquatic biota in the CAWS, but navigation clearly presents significant limitations to aquatic biota in the CAWS. Furthermore, the channel design/modification to support navigation presents significant limitations to the habitat improvement potential in the CAWS.

4.3 CONTRAST BETWEEN CAWS AND NATURAL RIVERS

The assessment of habitat in the CAWS cannot ignore two key aspects of the system:

- ***Most of the system is manmade.*** Seventy-five percent of the CAWS is not natural, having been excavated to provide conveyance of treated wastewater and urban drainage away from Lake Michigan and support commercial navigation. The design of the manmade channels of the CAWS, particularly the Chicago Sanitary and Ship Canal and the Cal-Sag Channel, incorporates qualities to support their function which are at odds with habitat qualities found in natural systems. The rest of the system has been so modified that it bears little resemblance to its original form. These facts should not be overlooked and must be considered when evaluating the habitat of the CAWS.

- ***The primary uses of the CAWS today are effluent conveyance, navigation, and flood control.*** Not only was the system designed and built for these

> purposes, but it continues to function primarily to serve these purposes today. Access to the CAWS is structurally controlled by locks, dams, and pumping stations and every connection point to external water systems. Most of the flow in the CAWS at any given time is treated effluent from water reclamation plants, not natural flow from a watershed. The hydrology of the CAWS is completely manipulated to support these uses.

The constructed and heavily modified conditions within the CAWS, combined with the management of the system for its intended uses of wastewater conveyance and navigation, have limited the structural and functional conditions for aquatic habitat. These limited habitat features have resulted in a biotic community (as measured by fish) that is tolerant of the modified conditions. These conditions also impose a significant limitation on the potential of the CAWS to support fish communities different than what presently exist there.

5. DESCRIPTION OF AQUATIC BIOTA IN THE CAWS

As stated elsewhere in this report, the District has collected fish and macroinvertebrate data in the CAWS for several years. For purposes of this Study, data collected since 2001 were used, in order to reflect current conditions. These data are briefly described in this section.

5.1 FISH

The District has been collecting fish data annually since 1974 (with the exception of 1981 and 1982) within the Study area. However, to focus this Study on current conditions, the fish data analysis is limited to the data collected between 2001 and 2008. Fish data collected from 2001-2007 were used to analyze physical habitat data and develop a draft physical habitat index for the CAWS, while the 2008 fish data were used as the validation dataset.

5.1.1 Sources of Data

Between 2001 and 2008, the District collected fish data at 34 stations within the CAWS (Figure 3-1) on a routine basis. Twenty-three of these 36 stations are part of the District's Ambient Water Quality Monitoring (AWQM) program and those stations were used in the development of the habitat index for the 2001-2007 sample period. In 2008, five supplemental stations within the managed portion of the system were included in the fish sampling regime in an attempt to capture system habitat variation that may not have been included previously. The 2008 fish sampling included a total of 20 fish sampling stations within the Study Area. In total, 38 stations have been sampled for fishes within the Study Area during the 2001-2008 period (Table 5-1). The sample collections and processing follow the protocol described in Section 3.3.1.

Table 5-1: CAWS Fish Sampling Events, 2001 – 2008 (the numbers in the table represent species richness and total number of individuals in parentheses).

Stn. ID	Station Description	2001	2002	2003	2004	2005	2006	2007	2008
35	North Shore Channel at Central Street	12 (132)				11 (139)			8 (48)
36	North Shore Channel at Touhy Avenue	11 (596)	12 (147)	14 (335)	11 (249)	9 (276)	16 (496)	14 (387)	14 (68)
37	North Branch Chicago River at Wilson Avenue	9 (75)				11 (122)			
39	South Branch Chicago River at Madison Street		10 (138)				6 (99)		
40	Chicago Sanitary and Ship Canal at Damen Avenue		10 (148)				12 (164)		19 (277)
41	Chicago Sanitary and Ship Canal at Harlem Avenue	9 (88)	11 (188)	10 (225)	13 (193)	14 (758)	15 (388)	12 (282)	12 (186)
42	Chicago Sanitary and Ship Canal at Route 83		5 (32)				5 (10)		
43	Calumet-Sag Channel at Route 83			7 (43)				9 (261)	
46	North Branch Chicago River at Grand Avenue	12 (53)	7 (28)	8 (67)	9 (88)	5 (77)	10 (158)	13 (117)	6 (59)
48	Chicago Sanitary and Ship Canal at Stephen Street		4 (24)				5 (24)		4 (9)
56	Little Calumet River at Indiana Avenue			17 (452)				18 (322)	13 (81)
58	Calumet-Sag Channel at Ashland Avenue			13 (95)				12 (131)	
59	Calumet-Sag Channel at Cicero Avenue	10 (127)	13 (174)	12 (56)	10 (147)	10 (453)	15 (214)	12 (297)	4 (66)
73	North Branch Chicago River at Diversey Parkway	7 (58)				13 (164)			10 (36)
74	Chicago River at Lake Shore Drive		8 (22)				7 (83)		
75	Chicago Sanitary and Ship Canal at Cicero Avenue	10 (118)	10 (138)	9 (138)	13 (191)	7 (184)	11 (205)	13 (280)	11 (58)
76	Little Calumet River at Halsted Street	16 (210)	17 (163)	13 (219)	17 (207)	19 (913)	22 (405)	21 (281)	12 (45)
92	Chicago Sanitary and Ship Canal/Lockport (16th St)	2 (77)	6 (67)	7 (67)	4 (22)	9 (179)	8 (64)	6 (64)	10 (171)
99	Bubbly Creek at Archer Avenue		3 (21)				13 (158)		5 (8)
99.1	Bubbly Creek at I-55			6 (31)	10 (60)	5 (31)			
99.2	Bubbly Creek at 35th St			5 (39)	8 (77)	5 (26)			
99.3	Bubbly Creek at RAPS			7 (151)	10 (97)	5 (62)			
100	Chicago River at Wells Street		11 (136)				10 (250)		9 (27)
101	North Shore Channel at Foster Avenue	15 (179)				17 (273)			14 (115)
102	North Shore Channel at Oakton Street	2 (2)				17 (151)			
108	South Branch Chicago River at Loomis Street		10 (76)				13 (142)		
Supl.	Calumet-Sag Channel at 104th Street							10 (92)	
Supl.	Calumet-Sag Channel at Kedzie Avenue							8 (87)	
Supl.	Calumet-Sag Channel at Southwest Highway							13 (127)	
S1	Chicago Sanitary and Ship Canal at Bedford Park								16 (118)
S2	Chicago Sanitary and Ship Canal at Willow Springs								2 (7)
S3	Calumet-Sag Channel at Palos Hills								9 (53)
S4	Calumet-Sag Channel at Worth and Palos Heights								7 (50)
S5	Calumet-Sag Channel at Alsip								10 (74)
SEPA2	Little Calumet River at SEPA 2					16 (529)	12 (218)		
SEPA3	Calumet-Sag Channel at SEPA 3			13 (148)		16 (253)		14 (407)	
SEPA4	Calumet-Sag Channel at SEPA 4			11 (93)	11 (82)	14 (663)	9 (79)	15 (417)	
SEPA5	Calumet-Sag Channel at SEPA 5			12 (232)	7 (41)	16 (443)	7 (37)	17 (216)	
SEPA5_CSSC	Chicago Sanitary and Ship Canal at SEPA 5			5 (18)	8 (53)	6 (306)	8 (34)	9 (178)	

5.1.2 Summary Description

Fifty-two (52) species, including five hybrids, of fish were identified at the 34 CAWS monitoring stations between 2001 and 2007 (sample period). For the 2001-2007 sample period, the number of non-hybrid species collected across the CAWS stations ranged from 27 at AWQM Station 76 (Little Calumet River at Halsted Street) to only five at Stephen Street (Chicago Sanitary Shipping Canal; CSSC). The most frequently observed species across all stations included gizzard shad (*Dorosoma cepedianum*), common carp (*Cyprinus carpio*), and largemouth bass (*Micropterus salmoides*), respectively (Figure 5-1). The most numerous observed species within the CAWS included gizzard shad (n=6906), emerald shiner (*Notropis atherinoides*; n=2082) and common carp (n= 2055), respectively (Figure 5-2). Eleven species are represented by only a single observation for the 2001-2007 period. Finally, gizzard shad, common carp, and largemouth bass have been observed at all stations during the sample period.

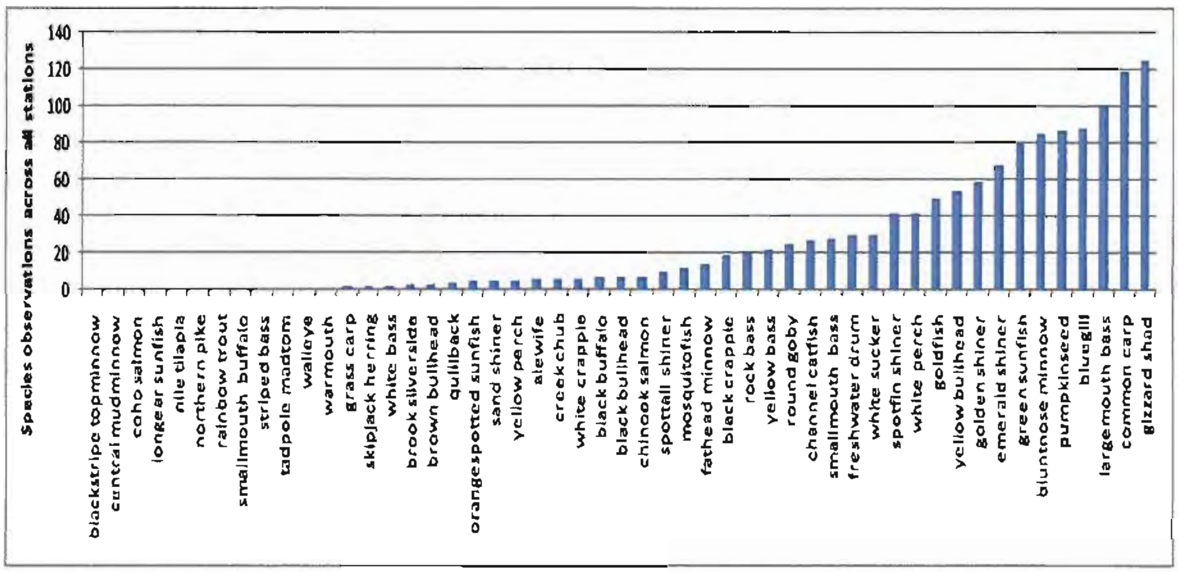

Figure 5-1: Non-Hybrid Fish Observations in CAWS Study Area, 2001-2007.

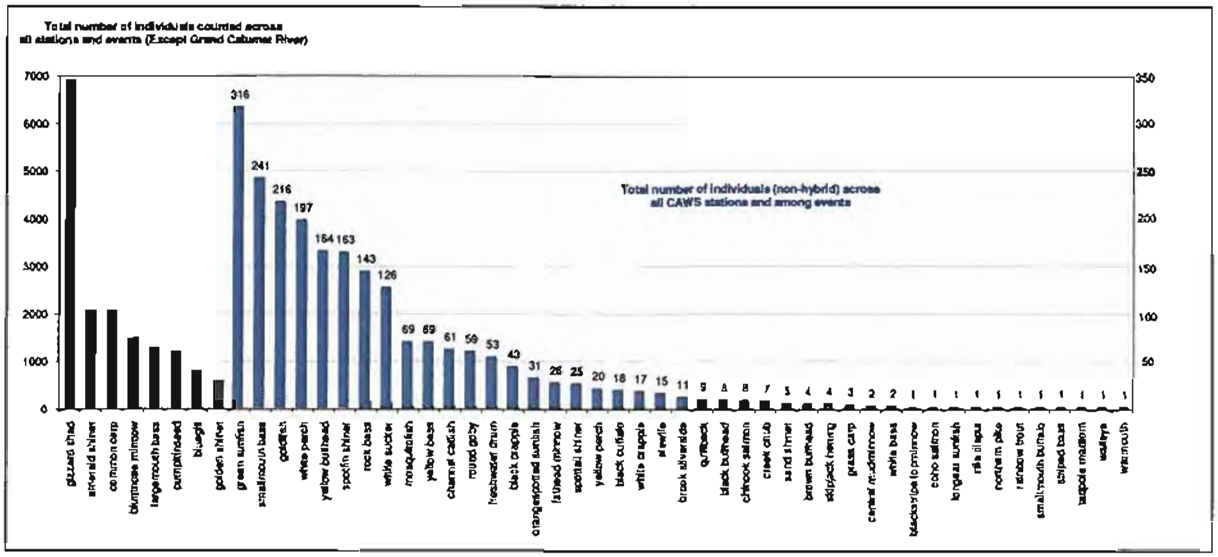

Figure 5-2: Total Number of Individuals (Non-Hybrids) Observed in CAWS Study Area, 2001-2007. (NOTE: the left-hand axis corresponds to the black bars and the right-hand axis corresponds to the blue bars).

The distribution and abundance of gizzard shad in the CAWS is not unusual for large water systems and Simon and Sanders (1999) suggest not including this species in community structure comparisons as a potential source of bias in analysis. Emerald shiner is commonly found in large rivers and appears to thrive in reservoir systems (Becker, 1983), so their numbers and distribution within the CAWS is not unexpected. Common carp are found in turbid, warm, large river systems of the Midwest (Becker, 1983) and their distribution and abundance in the CAWS is also not surprising. Largemouth bass are also abundant in large rivers of the Midwest (Becker, 1983), with a presence expected in the CAWS and serve as a popular recreation target species within the system (Personal communication, Bradley, 2008). Pumpkinseed also appears to thrive in impounded systems (Becker, 1983) so their numbers and distributions are also not unexpected.

In 2008, 43 species were identified at the 20 stations sampled within the Study Area. Eleven of those species were identified as hybrids and the newly identified species included steelcolor shiner (*Cyprinella whipplei*), not previously identified within the Study Area.

The 2008 fish data included up to 19 species at the Damen Avenue station on the CSSC and as few as 2 species at Supplemental Station 2 (Willow Springs) on the CSSC. The most numerous species were gizzard shad, common carp, bluntnose minnow and pumpkinseed.

5.1.3 Summary of Metric Selection

Fish metric selection and calculation is a common form of fish data analysis (Flotemersch et al. 2006). The general approach for screening fish metrics to determine useful and appropriate measures for the CAWS followed methods applied in development of fish IBIs, as documented in peer-reviewed scientific literature. The objective of this process was not to develop a new IBI for the CAWS, but the process of metric development involves review, analysis, and reduction of fish metrics, so the methods used in the literature to develop IBIs provided a sound basis for screening of metrics as appropriate descriptions of the fisheries data for the CAWS.

The fish dataset used in the metric selection included CAWS fisheries data collected by the District between 2001 and 2007. The general procedures for selecting an appropriate set of fish metrics included the selection of a set of candidate metrics, the screening of candidate metrics and the final selection of representative fish metrics that are sensitive and respond to both physical and water quality changes. In summary, a starting list of 46 metrics was established from previous studies (Lyons et al., 2001; IDNR, 2000; OEPA, 1989; Karr, 1981). These 46 metrics were then screened through various procedures for metric removal (e.g., those lacking data, tests for metric redundancy and tests of variance sensitivity), resulting in a final list of twelve metrics (Table 5-2). The retained metrics are representative of each of the five ecological function categories as recommended by Simon and Lyons (1995), Lyons et al. (2001), Roset et al. (2007): species richness and composition (SRC), indicator species (ISM), trophic function (TFM), reproductive function (RFM), and individual abundance and condition (ACM).

Table 5-2: Selected CAWS Fish Metrics.

Fish Metric	Ecological Function Category[6]
% Diseased or with eroded fins, lesions, or tumors	abundance and condition metric (ACM)
catch per unit effort	abundance and condition metric (ACM)
% lithophilic spawners by count	reproductive function metric (RFM)
% Insectivores by count	trophic function metric (TFM)
% top carnivores by weight	trophic function metric (TFM)
proportion of Illinois tolerant species	indicator species metric (ISM)
IL ratio of non tolerant coarse-mineral-substrate spawners	reproductive function metric (RFM)
number of IL native minnow species	species richness and composition metric (SRC)
number of IL native sunfish species	species richness and composition metric (SRC)
IL ratio of generalist feeders	trophic function metric (TFM)
% intolerant species by count	indicator species metric (ISM)
% moderately intolerant species by weight	indicator species metric (ISM)

5.2 MACROINVERTEBRATES

The Metropolitan Water Reclamation District of Greater Chicago (District) has been collecting macroinvertebrate data annually since 2001 within the Study Area. Given that the focus of this Study is on current conditions, the macroinvertebrate data analysis is limited to the data collected between 2001 and 2007. This data set, as mentioned in Section 3.1.2 was used to select CAWS appropriate macroinvertebrate metrics, compare collection methods using the selected metrics, and evaluate deformities as related to water quality and contaminated sediment.

5.2.1 Sources of Data

All macroinvertebrate data comes from District collected samples from the 2001-2007 sample period. For the sample period, the Study area includes data from 22 sample stations using Hester Dendy collected data and 24 stations were included using Ponar grab sampler data.

[6] ACM = abundance and condition metric; RFM = reproductive function metric; TFM = trophic function metric; ISM = indicator species metric; SRC = species richness and condition metric.