BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
WATER QUALITY STANDARDS AND	)	R08-9
EFFLUENT LIMITATIONS FOR THE	)	(Rulemaking - Water)
CHICAGO AREA WATERWAY SYSTEM	)	
AND THE LOWER DES PLAINES RIVER:	)	Subdocket C
PROPOSED AMENDMENTS TO 35 Ill.	)	
Adm. Code Parts 301, 302, 303 and 304	)	

NOTICE OF FILING

To: ALL COUNSEL OF RECORD
(Service List Attached)

PLEASE TAKE NOTICE that on the 2nd day of February, 2011, I electronically filed with the Office of the Clerk of the Illinois Pollution Control Board, the **Pre-Filed Testimony of Scott B. Bell – Chicago Area Waterway System Habitat Evaluation and Improvement Study.**

Dated: February 2, 2011.

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

By: *\/s/ Fredric P. Andes*
One of Its Attorneys

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PROOF OF SERVICE

The undersigned attorney certifies, under penalties of perjury pursuant to 735 ILCS 5/1-109, that I caused a copy of the foregoing, **Notice of Filing** and **Pre-Filed Testimony of Scott B. Bell – Chicago Area Waterway System Habitat Evaluation and Improvement Study**, to be served via First Class Mail, postage prepaid, from One North Wacker Drive, Chicago, Illinois, on the 3rd day of February, 2011, upon the attorneys of record on the attached Service List.

/s/ David T. Ballard
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BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

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PRE-FILED TESTIMONY OF SCOTT B. BELL

CHICAGO AREA WATERWAY SYSTEM HABITAT EVALUATION AND IMPROVEMENT STUDY

My name is Scott B. Bell and I am a consulting environmental engineer with LimnoTech, Inc., where I hold the title of Vice President. I am also part owner of LimnoTech. I am a licensed Environmental Engineer and I am a Board-Certified Environmental Engineer by the American Academy of Environmental Engineers. I have 21 years of experience evaluating impacts of human activity on water resources, including 2 years graduate research and 19 years consulting practice. I have a Bachelor of Science degree in environmental studies from the State University of New York College of Environmental Science and Forestry in Syracuse, New York, and a Master of Science degree in civil engineering from the University of Maine at Orono, specializing in water resources. Further details of my professional education and experience are presented in Attachment 1.

Since May 2008, I have been the project manager of the Chicago Area Waterway System (CAWS) Habitat Evaluation and Improvement Study (the CAWS Habitat Study), under contract to the Metropolitan Water Reclamation District of Greater Chicago (the District). This testimony summarizes the major findings of the CAWS Habitat Study and presents additional information supporting those findings.

Overview

The CAWS Habitat Study was a thorough and data-intensive examination of the relationships between fish, physical habitat, and water quality in the CAWS. The CAWS Habitat Study used eight years of fisheries, water quality, and physical habitat data collected by the District, as well as new data collected specifically for the study. These data were evaluated using analytical methods appropriate for this type of ecological evaluation. The CAWS Habitat Study produced several significant findings regarding physical habitat in the CAWS, its relative importance to fish, and the potential for improving fisheries in the CAWS. Specifically:

- 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.
- There is limited potential for physical habitat improvement in the CAWS and potential changes might not result in measureable improvements to fisheries. Only

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

Additional information regarding the major findings listed above is presented in the following sections of this testimony.

1. Inherent Limitations on Habitat in the CAWS

In any discussion of aquatic ecology and physical habitat in the CAWS it is important to remember the anthropogenic origin of much of the system. Of the roughly 78 miles of waterways included in the CAWS Habitat Study, approximately 75% are manmade canals that were excavated in the late 19th and early 20th centuries to convey wastewater effluent and urban storm water away from Lake Michigan and to support commercial navigation. While about 75% of the CAWS are manmade, the other 25% of the waterways have been extensively modified from their original form to also support these uses. Many miles of channel banks were dug into bedrock; where the channels were dug in soil the banks were armored with stone and other materials to prevent erosion. As part of the CAWS Habitat Study, we conducted a digital video survey of the entire system, wherein the entire length of each bank of the system (156 miles of bank in total) was digitally videoed in conjunction with global positioning system (GPS) equipment. This not only created a digital record of bank conditions throughout the entire system, but also allowed us to make accurate measurements of bank types for the entire system, not just at certain locations. Using these data, we determined that 61% of the banks in the CAWS (approximately 95 miles) consist of vertical walls or are covered with riprap.

The constructed reaches of the CAWS were made uniform in shape and relatively straight, which imposes limitations on aquatic life. Where natural channels previously existed, the channels were also straightened. In rivers and streams, the curving of the channels as they flow through the landscape creates variations in flow velocity, water depth, bed materials and essentially creates variations in habitat that support a variety of aquatic life and life stages. This is an essential aspect of aquatic habitat in rivers and streams and replication of this sinuosity is often a specific goal in stream restoration when the goal is to restore habitat. Sinuosity is typically measured as the actual length of the channel between two points, divided by the distance between the two points as the crow flies. Using this measure, a perfectly straight channel will have a sinuosity of one and the more sinuous the channel, the higher the value. In rivers and streams, a sinuosity less than 1.2 is considered low, while sinuosity greater than 1.5 is considered high. Most of the reaches of the CAWS have a sinuosity between 1.0 and 1.1.

The channels of the CAWS were also constructed and are maintained to be relatively deep, to provide sufficient capacity for the conveyance of wastewater effluent and storm water runoff from the City of Chicago and to allow commercial shipping. Most of the channels in the CAWS are 15 feet deep or more and not only in the center, where rivers are deepest, but across nearly their entire widths. Many of the channels were made to be roughly rectangular or trapezoidal in cross-section with very little of the shallow, nearshore areas, called littoral zones, that are typically very important to fish in natural systems. In addition, a large portion (approximately 78%) of the CAWS is maintained for navigation by the U.S. Army Corps of Engineers, although it has not been necessary to actually dredge these channels in many years.

Channel substrate (the composition, texture and structure of bed materials) is a very important aspect of physical habitat in aquatic systems. Typically, substrate that includes relatively large portions of sand and gravel is considered preferable habitat. As part of the CAWS Habitat Study, substrate data from 28 stations throughout the CAWS were evaluated. Substrate at most of these stations (16 out of 28) was characterized as “inorganic silt”, indicating a very fine material, finer than sand. Five of the stations were found to have beds characterized as bedrock, which is also relatively undesirable from a habitat perspective. In addition to being poor in composition and texture, the substrate in the CAWS contains widespread contamination from industrial and other human activities. Chemicals detected at elevated levels in sediments throughout the CAWS include petroleum products, pesticides, polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs), and heavy metals. Analysis conducted as part of the CAWS Habitat Study showed that there are statistically significant relationships between the concentrations of many these chemical and the health of benthic invertebrates, which comprise a key part of the food chain in aquatic systems.

In rivers and streams, connection to the floodplain is not only important for the system’s hydrology but it is important for aquatic biota. For fish, floodplains can provide seasonal habitat diversity, as well as a source of organic and inorganic materials required by various organisms in various life stages. Research has shown that disconnection of natural rivers from their floodplains can lead to lower fish diversity. Floodplains never existed for the 75% of the CAWS that were excavated where channels did not previously exist, such as in the Cal-Sag Channel and the Chicago Sanitary and Ship Canal. In the CAWS reaches that were once natural waterways, or partially so, channelization has eliminated floodplain connectivity almost entirely. The absence of floodplains and floodplain connectivity in the CAWS is, for the most part an irrevocable condition.

The design of the waterways was intended to support their primary uses and not to mimic natural waterways. Their form limits bank and benthic habitat and minimizes hydraulic and geomorphic variation in the channels, which are very important to aquatic life. The CAWS Habitat Study found that channel depth, lack of off-channel areas and bank refuge for fish, vertical-walled or riprapped banks, and manmade structures in the channels were all strongly, negatively correlated with fish condition. All of these factors are attributable to the design of the CAWS and the fact that they are entirely manmade or drastically modified in form.

In addition to the limitations imposed by the form of the waterways, the primary uses of the CAWS further limit their ecological potential. The inflow of urban stormwater carries fine sediments. A portion of this fine sediment load settles to coat the bed of the waterways, while the rest remains in suspension, resulting in relatively high turbidity. Part of the sediment that settles is easily resuspended by currents or passing boats and barges. These sediments carry pollutants from the urban environment which add to the contaminants already present in the sediments from years of industrial discharges. The CAWS Habitat Study (Report submitted January 6, 2010 as part of Public Comment No. 284) found that sediment contamination was statistically correlated to poor invertebrate condition. Navigation also has a significant negative impact on fish in the CAWS. CAWS reaches with high commercial navigation were found to have a statistically significant poorer fisheries condition than those reaches without high 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. 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. Although navigation was not measured as part of the CAWS Habitat Study, commercial 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 indicate that millions of tons of commercial cargo pass through the Chicago Sanitary and Ship Canal, the Cal-Sag Channel, and the Little Calumet River each year. Channel modifications to support navigation were discussed previously in this testimony, but there are also direct negative impacts on fish including propeller impacts and the effects of increased velocities, shear stresses, wake impacts, and noise that passing vessels can cause, all of which can be harmful to fish. These effects are likely exacerbated by the uniform shape of the CAWS channels and relative lack of refuge for fish.

These observations and findings of the CAWS Habitat Study all support the conclusion that aquatic habitat is inherently limited in the CAWS by the system's form and function.

2. Relative Importance of Physical Habitat to Fish in the CAWS

A key objective of the CAWS Habitat Study (Report submitted January 6, 2010 as part of Public Comment No. 284) was to evaluate the importance of physical habitat to fish in the CAWS, relative to dissolved oxygen (DO). Key physical habitat and DO variables were independently identified and then statistically compared to fish data. A "combined fish metric" was developed as part of the CAWS Habitat Study which served as a CAWS-specific index of biological integrity for fish. It was found that the CAWS combined fish metric was, in many cases, positively correlated with DO, but the correlations were relatively weak, with r-squared values ranging from 0.02 to 0.27.

Multiple linear regression was used to compare habitat variables with the same combined fish metric to which DO was compared. This analysis showed that a set of six key habitat variables (maximum channel depth, number of off-channel bays, percent of vertical walled banks, percent of riprap banks, manmade structures, and macrophyte cover) were the most strongly correlated with the combined fish metric. This correlation had an r-squared of 0.48, indicating that these habitat variables explain as much as 48%, or about half, of the variability in the fish data, compared to 0.27 for the best-correlated DO variable. Thus, it was shown that physical habitat is a more important indicator of fisheries condition than DO in the CAWS. When the key DO variable (percent of time from June through September that DO was < 5 mg/L) was added to the regression equation with the six key physical habitat variables, the r-squared of the resulting regression equation was only increased by 4%.

A logical question arising from this analysis was this: if physical habitat alone can, at best, explain about half of the variability of fish data in the CAWS, what can explain the other half? To answer this, statistical analyses were conducted between the regression residuals, which represent the portion of the data not explained by the regression, and the best-correlated DO variable. This comparison results in an r-squared of 0.03, indicating that the key dissolved oxygen variable identified in the study only explained 3% of the fish data variability that is not explained by physical habitat. This further supported the finding that physical habitat is relatively more important to fish in the CAWS than dissolved oxygen.

It is worth noting that a similar statistical comparison was performed between the regression residuals and the temporal variability of the fish data at each station. This was done because it was noted that there was an inherent variability in fish metrics at each sampling station from year to year. This variability is not unusual with fish data, since fish are mobile and their presence at a given location at any point in time is attributable to a variety of factors. This analysis showed that most of the variability in fish data not explained by the key habitat variables can be explained 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. 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.

In addition to the multiple linear regression analysis, the data were analyzed using classification and regression tree (CART) analysis as a complementary method of evaluation (Attachment 2). CART analysis is frequently used in ecological studies to identify limiting factors, which are defined as environmental elements that are most important to organisms in a particular ecosystem (e.g. light as the limiting factor in understory plant growth in rain forests). The CART analysis was conducted using 40 physical habitat variables and six DO variables. The outcome of the analysis was that, of the combined list of 46 habitat and DO variables, two habitat variables (maximum channel depth and percent overhanging vegetation) were the most important factors in describing fish data from the CAWS. A DO variable (percent of time from June through September that DO was < 5 mg/L) appeared as the third most important variable, but only for 64 out of 101 samples. These results corroborate the finding of the multiple linear regression analysis that physical habitat is relatively more important to fish in the CAWS than DO.

These statistical analyses clearly show that, under current conditions, physical habitat is relatively more important (i.e. more limiting) to fish in the CAWS than DO.

3. Potential Impacts of Habitat Improvement in the CAWS

As part of the CAWS Habitat Study, a system-specific habitat index was developed for the CAWS (Report submitted January 6, 2010 as part of Public Comment No. 284). This index, called the CAWS Habitat Index, includes the six key habitat variables that were found to be most strongly correlated with fish data (maximum channel depth, number of off-channel bays, percent of vertical walled banks, percent of riprap banks, manmade structures, and macrophyte cover). The strong statistical relationship between these habitat variables and fish in the CAWS was demonstrated by the relatively high r-squared value (0.48) determined by multiple linear regression. In addition to the six key variables, five additional variables (bank pocket areas, large substrate in shallow and deep parts of the channel, organic sludge, and overhanging vegetation) were added to the index to reflect other habitat attributes that were also important to fish in the CAWS but to a lesser degree than the six key variables. When compared to fish data from the CAWS, the index developed using these 11 habitat variables had an r-squared value of 0.48.

The r-squared yielded by the CAWS Habitat Index (0.48) is very good compared to similar r-squared values yielded for development of other published habitat indices. For example, the Qualitative Habitat Evaluation Index (QHEI) developed in Ohio and widely used elsewhere, had an r-squared of 0.45 with its original development dataset (Rankin, 1989). When two other existing habitat indices (the QHEI and the Michigan Non-Wadeable Habitat Index) were applied to the CAWS and the results compared to actual CAWS fish data using linear regression, they yielded relatively poor r-squared values (0.02 and 0.04, respectively) (Attachment 3). The r-squared of 0.48 for the CAWS Habitat Index is more than ten times higher than these values, validating its superiority for evaluating the relationship between physical habitat and fish in the CAWS.

One of the primary values of the CAWS Habitat Index is that it is based on the specific habitat attributes that are most important to fish in the CAWS. Using the CAWS Habitat Index, one can quantify those important habitat attributes at any site or in any reach and understand which are most limiting to fish at that location. Furthermore, with that understanding of the quality of the most important habitat attributes, one can assess the degree to which one or more of those habitat attributes can be improved at that location and calculate the probable effect of the habitat improvement on the index score for that location. This provides a means of indirectly quantifying the potential for fisheries improvement through habitat improvement. This is exactly the approach that was used in the CAWS Habitat Study (Report submitted January 6, 2010 as part of Public Comment No. 284).

The CAWS Habitat Index was calculated for each major reach of the CAWS. Representative values for each habitat variable represented in the index were determined from the extensive data collected during the CAWS Habitat Study to yield the most accurate representation of each reach possible with available data. Each habitat variable was then evaluated for each reach, in the context of the form and function of the reach and in light of other probable constraints, to make a realistic quantitative estimate of the potential for improvement of the habitat variable. Because each of the habitat variables in the CAWS Habitat Index is represented in the index as a measured quantity, as opposed to a qualitative or descriptive variable, the determination of index values is quite precise. Furthermore, this attribute of the index makes it relatively easy to calculate the change in the index resulting from habitat improvements.

It should be noted that, although the habitat variables used in the index are based on measureable quantities, there is a relatively high degree of uncertainty with respect to estimating the degree of improvement that can actually be made within the CAWS. The potential for improvement of any of the habitat variables is dependent on numerous, uncertain factors making it difficult to precisely estimate the extent of improvements. Consequently, much of the potential improvement that is estimated in the report is based on "professional judgment" and not any precise computation or assessment.

The change in CAWS Habitat Index scores resulting from potential habitat improvement varied among CAWS reaches, from zero change in the Chicago River to a calculated 38% change in the Cal-Sag Channel. It should be noted that some of the assumptions made in this study related to habitat improvement potential may not be realistic. For example, in the Habitat Improvement report, it is estimated that proposed improvements would increase the habitat index score from 34 to 47 (38% increase) for the South Branch Chicago River. In this case, the estimated increase in habitat index score for the South Branch Chicago River is largely predicated on the assumption that half of the vertical side walls can be removed and improved, which may not be feasible.

In general, the reaches that had the lowest starting score with the CAWS Habitat Index showed the greatest improvement potential as a percentage of the original score. These results are presented in the Habitat Improvement Report (Report submitted January 6, 2010 as part of

Public Comment No. 284). It should be noted that, although this analysis may be useful in prioritizing the CAWS reaches for habitat improvement, it does not provide direct information about the potential benefits of the habitat improvements to the biological community. Although the CAWS Habitat Index provides a quantitative method of measuring habitat using attributes that are clearly important to fish in the CAWS, there may be other factors, not accounted for in the index, that limit the potential for improving fish populations. The presence of high navigation was found to be a significant limiting factor for fish in the CAWS, but it is not accounted for in the index. There is no way to know whether the continued use of a given reach for commercial navigation, for example, might negate the benefits of potential habitat improvements. Other examples include the presence of extensive sediment contamination or the localized effects of sudden, high velocity flows, such as occur in Bubbly Creek when the Racine Avenue Pumping Station (RAPS) is activated.

No clear and reliable way to define the potential biological benefit of habitat improvement was identified in the CAWS Habitat Study. A certain degree of habitat improvement in the CAWS might result in no improvement in fish, slight improvement, or although unlikely, significant improvement. One simple way of looking at this is to assume, hypothetically, that the improvement in fish would be equivalent to the improvement in habitat, as measured by the CAWS Habitat Index. If this were to be the case, the potential improvement in fish populations would range from zero to 38%, since this would be the range of improvement in the CAWS Habitat Index if all of the habitat improvements identified in the CAWS Habitat Improvement Report (Report submitted January 6, 2010 as part of Public Comment No. 284) were made.

Two important points should be noted here. First, a cluster analysis of the fish data used in this study (Attachment 4) indicates that a dominant fish community occurs throughout the CAWS, suggesting a degree of stability in the fish community. In light of this, it is unlikely that the small increases in habitat score discussed here would likely result in significant change in fish community (i.e. new species or significant change in relative proportion of existing species). Second, it should be noted that the available data used in this study did not allow the direct linkage of habitat variables to specific habitat function; therefore it is not clear if potential improvements would have any direct improvement on habitat function in CAWS.

One question that arises is whether the improvements in fish would be measureable. Because the existing fish data from the CAWS exhibits significant variability over time, it is uncertain whether observed changes in fish populations where habitat improvement is implemented could be attributed to the habitat improvement or simply to natural variability. To illustrate this challenge in measuring the benefit of potential habitat improvement, the percent change in CAWS habitat index resulting from potential habitat improvement in each reach was compared to the coefficient of variability for the actual fish data from each reach. The coefficient of variation is a standard measure of the variability of data; the smaller the coefficient of variability, the more constant the quantity being measured. For the CAWS fish data collected between 2001 and 2008, the coefficient of variability ranges from 79% to 534%. In most cases, the coefficient of variation of the fish data is an order of magnitude greater than the percent change in habitat index score, suggesting that the natural variability of the fish data may overshadow any potential change in fisheries that might result from habitat improvement.

Respectfully submitted,

By: Scott B. Bell
LimnoTech

Testimony Attachments

1. Scott B. Bell curriculum vita
2. Technical Memo on CART Analysis
3. Technical Memo on Evaluation of Other Habitat Indices in the CAWS
4. Technical Memo on Fish Cluster Analysis

REFERENCES

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MS Civil Engineering
The University of Maine, Orono, Maine, 1992

BS Environmental Studies, *Magna Cum Laude*
The State University of New York, College of Environmental Science & Forestry, Syracuse, New York, 1988

Registration/Certification

Professional Engineer, Licensed in Michigan (1995 - #41558) and Illinois (1996 - #062-053072)

Board Certified Environmental Engineer (BCEE), American Academy of Environmental Engineers

Experience Summary

Mr. Bell manages LimnoTech's practice in watersheds and waterways. He has more than 18 years' consulting experience in water resources engineering and analysis which includes aquatic ecosystem assessment and modeling, environmental hydraulics and hydrology, flood analysis, stormwater management, best management practice (BMP) design, lake study, dam engineering, drainage evaluation and design, erosion analysis, wastewater discharge evaluation and permitting, mixing zone analysis, hydrogeological studies, and ecosystem restoration. He has planned and executed dozens of water resource projects in more than 20 states, including work in the Gulf of Mexico, the Great Lakes, and the Atlantic and Pacific Oceans. In addition, he has managed more than 100 environmental and water resource investigation and/or improvement projects.

Professional and Academic Appointments

Vice President 2007-Present	LimnoTech Ann Arbor, Michigan
Senior Manager 2003-2007	LimnoTech Ann Arbor, Michigan
Adjunct Lecturer 2002-2003	The University of Michigan Dept. of Civil and Environmental Engineering Ann Arbor, Michigan

Senior Engineer 1999-2003	LimnoTech Ann Arbor, Michigan
Project Engineer 1995-1999	LimnoTech Ann Arbor, Michigan
Staff Environmental Engineer 1992-1995	LimnoTech Ann Arbor, Michigan
Graduate Teaching and Research Assistant 1990-1991	University of Maine, Dept. of Civil Engineering Orono, Maine

Professional Activities

Board of Directors: Society of American Military Engineers, Detroit Post. 2004-2007.

Hazardous Waste Management Subcommittee, American Academy of Environmental Engineers: November 2001 to 2006.

Instructor: Engineering Society of Detroit. *Professional Engineer Licensing Review Course - Hydraulics, Hydrology and Drainage*, 2001 - 2004.

Adjunct Lecturer: The University of Michigan Department of Civil and Environmental Engineering. *CEE 402: Professional Issues and Design (senior design course)*, Winter 2002, Winter 2003.

Instructor: Engineering Society of Detroit. *Industrial Wastewater Treatment Plan Operator's Certification Training Course - Groundwater Pump and Treat Systems*, 1995 - 1999.

Publications

Where Do We Put It? Challenges and Strategies for Finding Sites for BMP Implementation and Retrofits. Watershed and Wet Weather Bulletin of the Water Environment Federation. March/April 2006.

Inventorying Sreambank Erosion Conditions: The Rouge Main 1-2 Project. Pipeline (Journal of the Michigan Association of County Drain Commissioners). v15 n1, First Quarter 2006.

Evaluation of Assimilative Capacity For Developing Water Quality-Based Effluent Limits For Petroleum Refinery Discharges, American Petroleum Institute, 2006.

"Managing Water Discharges," Chapter 15 in the *Handbook of Hazardous Materials Management*: Published by the Institute for Hazardous Materials Management (2002).

A Preliminary Assessment of the Fate and Transport of Hexazinone in Groundwater at Pineo Ridge Glacial Delta: Masters' Thesis submitted in partial fulfillment of the Master of Science Degree in Civil Engineering, University of Maine, 1992.

Conference Proceedings/Presentations

An Innovative Approach to Identifying Opportunities for Non-Point Source Pollution Control Across Multiple Watersheds, Presented at WEFTEC 2009, Orlando, Florida, October 2009.

Development of a System-Specific Habitat Index for an Urban Waterway System in Chicago, IL, Presented at the 3rd National Conference on Ecosystem Restoration, Los Angeles, California, July 2009.

Urban Stream Restoration: Challenges and Strategies, Presented at the North Carolina Stream Restoration Institute Conference, Charlotte, North Carolina, October 2006.

Evaluating the Potential of Wetland Restoration as a Method of Improving Water Quality in Eutrophic Lakes, Presented at the Association of State Wetland Managers Conference, Traverse City, Michigan, August 2006.

Identifying and Prioritizing Water Resource Improvement Projects: Challenges, Tools and Strategies, Presented at the Michigan Association of Counties Summer Conference, August 2005.

Large Scale Groundwater Withdrawals in the Great Lakes – Is There a Need for Regulation…or is Something Else Needed?, Presented at the Michigan Chamber of Commerce *Environmental Issues Forum,* 2005.

Mercury, Mercury, Everywhere!, Presented at the Michigan Chamber of Commerce *Environmental Issues Forum,* 2004.

Discharger Led TMDL Study for Findley Lake Watershed, Ohio (How to Get a NPDES Permit for a 303(d) Listed Water When the TMDL is Years Away). Breidenbach, V.K.S., S.B. Bell, D.W. Dilks. Proceedings of the Water Environment Federation TMDL Sciences Conference 2003, Chicago, Illinois. November 19, 2003.

Current Issues in Water Quality, Presented at the Michigan Chamber of Commerce *Environmental Issues Forum,* 2002 and 2003.

Evaluation of the Transfer Method for Estimating River Flows: Presented at *Watershed 2002,* a specialty conference of the Water Environment Federation, Fort Lauderdale, FL. February 2002.

Industrial Stormwater Permits: Presented at the Michigan Chamber of Commerce *Environmental Permitting Seminar,* August 1999.

Groundwater Treatment Fundamentals: Presented at the *Surface Water/Groundwater Workshop for Environmental Professionals,* sponsored by the Michigan Water Environment Association, March 1997.

Considerations for Accepting Leachate and Remediation Site Groundwater at Publicly Owned Treatment Works: Invited paper presented at the 1996 *Michigan Water Environment Association Annual Conference,* Mackinac Island, Michigan, June 1996.

Selected Project Experience

Ecological Engineering, Green Infrastructure, and Environmental Restoration

Constructed Wetland for Stream Water Quality Improvement, Covington, Kentucky. 2009 – 2010. Senior engineer and project manager for design and construction of a constructed wetland for treatment of stream flow. Work includes hydraulic & hydrologic analysis, wetland design, permit application and support, and development of operation and monitoring plan.

Green Infrastructure Evaluation, St. Louis, Missouri. 2008 - 2010. Senior engineer for evaluation of green infrastructure retrofitting to help control combined sewer overflows (CSOs). Planned and directed spatial and modeling analyses to determine the siting feasibility and potential effectiveness of green infrastructure retrofits.

Chicago Area Waterways Habitat Evaluation and Improvement Study, Chicago, Illinois. 2008 - 2010. Project manager for ecological study of the Chicago Area Waterways, nearly 90 miles of heavily modified urban waterways, to evaluate the present ecological condition and determine the potential for improvement of physical habitat to support fish. Project includes development and application of a customized habitat index for the system.

Green Infrastructure Evaluation, Ottawa, Illinois. 2009 – 2010. Senior technical consultant and reviewer for evaluation of green infrastructure retrofitting for combined sewer overflow (CSO) reduction.

Constructed Wetlands for Water Quality Improvement, Columbus, Indiana. 2010. Technical consultant and reviewer for preliminary design of constructed wetlands to treat diverted river water for a planned competitive water skiing facility.

Constructed Wetland for CSO Treatment, Alton, Illinois. 2009. Senior engineer for feasibility assessment and conceptual design of a constructed wetland for treatment of combined sewer overflows to a flood management area behind Mississippi River levees. Work includes site reconnaissance, data review and concept development, meetings with the U.S. Army Corps of Engineers and the Illinois Environmental Protection Agency, and preparation of language for the Long Term Control Plan.

Maumee Bay State Park Treatment Wetland, Oregon, Ohio. 2007 - 2008. Engineering consultant for conceptual design of constructed wetlands to reduce bacterial loading to Maumee Bay from non-point sources. Providing hydrologic and hydraulic modeling, as well as technical consultation on treatment design.

Consultation on Floodplain Restoration, McIntosh, Alabama. 2007. Technical consultant and reviewer for restoration of riverine floodplain with DDT-contaminated sediments. Provided senior review of engineering designs to improve habitat suitability for mosquito-fish.

Aquatic Vegetation Survey and Management Plan Development, Huron River, Michigan. 2006. Project manager for inventory and assessment of aquatic vegetation in three impoundments of the Huron River in Ann Arbor, Michigan. Worked with staff biologist to develop and evaluate management alternatives for macrophyte control.

River Bank Restoration and Stabilization, Rouge River, Michigan. 2005-2006. Project manager and senior engineer for engineering assessment and preliminary restoration & stabilization design for a reach of the Rouge River in Southfield, Michigan. Project included acquisition of field data & survey measurements, preliminary hydraulic analysis, geomorphologic assessment, and preparation of conceptual design.

Constructed Wetland for Stormwater Treatment, Wixom, Michigan. 2005-2006. Project manager and lead engineer for design and construction of a storm water treatment wetland in an existing dry detention basin.

Stormwater Detention Basin Retrofit, Wixom, Michigan. 2005-2006. Project manager and lead engineer for retrofitting an existing dry detention basin to wet detention, to improve phosphorus removal.

Constructed Wetland Design Evaluation, Grand Rapids International Airport, Michigan. 2005. Consulting engineer for management of airfield runoff. Provided technical evaluation and design recommendations for constructed wetland development to treat high BOD airfield runoff.

River Bank Inventory and Conceptual Designs, Rouge Main 1-2 Subwatershed, Oakland County, Michigan. 2004. Project manager and senior engineer for inventory studies in the Rouge Main 1-2 subwatershed, evaluating streambank erosion and detention pond conditions. Project involved inventory of more than 90 miles of stream and more than 350 detention ponds, preparation of a project database linked to a GIS interface, scoring and ranking of sites, and preparation of conceptual mitigation designs for problem areas.

BMP Siting and Conceptual Design Study, Kent Lake Subwatershed, Michigan. 2003. Project manager and senior engineer for development of conceptual BMP retrofit designs to reduce phosphorus loading to Kent Lake, a 303(d)-listed lake in the Upper Huron River watershed.

Pond Analysis and Wetland Retrofit Design, Parsons, West Virginia. 2003-2004. Project manager and lead engineer for technical evaluation of water quality management at a charcoal plant. Project included evaluation of existing conditions and development of design for conversion of stormwater pond system to a wetland system for water quality improvement.

Constructed Wetland Design for Landfill Leachate Treatment, Rockwood, Michigan. 2000-2001. Senior Engineer for design of a constructed wetland system to treat landfill leachate, utilizing physico-chemical removal and constructed treatment wetland technologies. Performed senior design review and checks on design calculations and drawings.

Floodplain and River Restoration Design, Black River, Michigan. 1999-2001. Project Manager and Senior Engineer for restoration design of a former dam impoundment, following remediation of contaminated floodplain sediments. Restoration design included river bank and floodplain restoration, as well as constructed off-channel ponds.

Hydrologic and Hydraulic Analysis

Hydrologic and Hydrodynamic Analysis, Wolf Creek/Berger Ditch/Maumee Bay, Oregon, Ohio. 2007 – 2008 (ongoing). Project manager and lead engineer for hydrologic and hydrodynamic study of the Wolf Creek/Berger Ditch watershed that flows through Maumee Bay State Park to Maumee Bay on Lake Erie. Work involved development of a hydrologic/hydraulic model using USEPA SWMM 5 and a hydrodynamic model of Maumee Bay using the USEPA Environmental Fluid Dynamics Code (EFDC).

Hydrologic Analysis, Round Lake, Michigan. 2006. Project manager and lead engineer for hydrologic study of a lake near Brighton, Michigan, to evaluate potential causes of apparent lake level decline.

Sediment Transport Investigation, St. Joseph River, Michigan. 2006. Project manager and lead engineer for sediment transport study on the St. Joseph River in Benton Harbor, Michigan. The study is in support of a permit application to the Corps of Engineers for a proposed marina development and includes sampling and analysis to determine bedload and suspended load sediment transport rates.

Hydrologic Study, Mill Creek Subwatershed, Michigan. 2005-2006. Principal investigator for hydrologic study of a 110 square mile subwatershed of the Huron River, including data compilation and analysis, model development and application, and assessment of hydrologic alteration within the basin. Project is being conducted *pro bono* for the Huron River Watershed Council.

Hydraulic Analysis & Bed Erosion Assessment, Huron River, Michigan. 2005. Project manager and senior engineer for engineering assessment related to removal of a concrete roadbed spanning the Huron River in Ann Arbor, Michigan. Project included channel survey, riverbed characterization, hydraulic analysis, and assessment of post-removal bed erosion potential.

Hydraulic Study for Proposed Brownfield Development, Saline River, Michigan. 2005. Project manager and senior engineer for hydraulic study of potential flood impacts of a proposed brownfield development on the Saline River. Project involved hydraulic modeling to determine flood elevations.

Hydraulic Analysis, Grand River, Michigan. 2004. Senior engineer for a hydraulic modeling analysis of alternatives to lessen the floodway impact of the proposed North Kent Sewer Authority wastewater treatment plant on the Grand River.

Floodplain Analysis of Proposed Development, Johnson Creek, Michigan. 2003-2004. Project manager and senior engineer for hydrologic study and flood evaluation for a proposed 400-acre mixed residential development on Johnson Creek, a tributary to the River Rouge. Project involved hydrologic modeling and hydraulic analysis to determine flood elevations.

Hydrologic Study and Dam Evaluation, Saline River, Michigan. 2003-2004. Project manager and senior engineer for engineering study of hydrologic impacts of a proposed 600-acre residential development on downstream conditions in the Saline River. Project involved hydrologic modeling, hydraulic analysis of dam spillway capacity, and redesign of dam spillway.

Lake Level Study, Silver Fox Lake, Michigan. 1999. Conducted a feasibility assessment to address low water conditions in a small inland lake. Evaluated technical effectiveness, implementability, and relative cost of different engineering alternatives.

Flood Assessment for a Private Residence, Ann Arbor, Michigan. 1998. Evaluated the future recurrence probability of flood conditions at a private residence on behalf of the homeowners. Conducted a hydrologic and hydraulic analysis to calculate flood levels at the property under a range of storm return periods.

Water Resources, Water Quality and Wastewater Engineering

Water Quality Modeling, Buffalo and Niagara Rivers, Buffalo, New York. 2008 - 2010. Project manager for development of water quality models of the Buffalo River, Niagara River, and Scajaquada Creek, to evaluate receiving water impacts from combined sewer overflows, as part of long-term control planning.

Ellerbe Creek Watershed Evaluation Study, Durham, North Carolina. 2008 - 2009. Project manager for watershed evaluations to address flooding and water quality issues. Work includes development and application of SWMM models to evaluate BMPs, as well as assessment of low impact development (LID) implementation and the potential benefit of LID practices.

Watershed Control Analysis and Design, Northern Kentucky Sanitation District No. 1. 2008 - 2009. Senior engineer for siting and design of regional treatment measures to control large-scale bacteria loading to receiving waters. Work involves site analysis, technical feasibility evaluation and conceptual design of regional detention facilities and constructed wetlands.

Charleston Harbor Outfall Preliminary Engineering Study, Charleston, South Carolina. 2007 – 2009. Project manager and senior engineer for a preliminary engineering study to evaluate the feasibility of constructing a new municipal wastewater outfall to Charleston Harbor. Work includes water quality and biological impact evaluations, modeling of effluent quality changes through tunnel, and permitting assessment.

Diffuser Evaluation and Mixing Zone Verification, Saginaw River, Michigan. Project manager and senior engineer for field evaluation and mixing zone modeling analysis of an industrial wastewater discharge to the Saginaw River. Designed field study to verify jet velocity characteristics of operating wastewater diffuser and used CORMIX model, in conjunction with field data, to analyze diffuser performance under permit conditions.

Ross Creek Watershed Planning Study, Asheville, North Carolina. 2007 – 2008. Project manager and senior engineer for watershed restoration studies on an urban creekshed in Asheville. Conducted water quality assessment and prepared a comprehensive water quality monitoring plan, conducted field evaluations of candidate sites for best management practices and restoration projects, prepared conceptual designs.

Assessment and Negotiation for Steel Mill NPDES Permit, Detroit, Michigan. 2007. Project manager and senior engineer for a review, assessment, and negotiation of NPDES permit for a steel mill in Detroit, Michigan.

Mixing Zone Study, San Francisco Bay, California. 2007. Senior engineer for modeling of municipal wastewater discharge from the Sausalito-Marin City Sanitary District. Planned and directed modeling of effluent dilution using USEPA Visual PLUMES.

Total Maximum Daily Load (TMDL) Development for Utah Reservoirs. 2007. Project manager and senior engineer for development of TMDLs for the Brough, Steineker, and Redfleet reservoirs in Utah, on behalf of the State of Utah.

Review of Deicing Control Design and NPDES Permit Requirements at the Springfield-Branson Regional Airport. 2006 - 2007. Senior engineer for technical review and consultation on stormwater permitting for the Springfield-Branson Regional Airport in Springfield, Missouri. Work included review of proposed air field runoff control strategies with respect to ability to achieve expected permit limits, review of monitoring data and advising on future data collection, and review of stormwater modeling conducted by engineering design firm.

Total Maximum Daily Load (TMDL) Development for Illinois Watersheds. 2006 - 2007. Senior technical consultant for development of TMDL Implementation Plans, following TMDL development for multiple watersheds in Illinois, under contract to Illinois EPA.

Wastewater Discharge Evaluation, Cooper River, Charleston, South Carolina. 2006. Project manager and senior engineer for a municipal wastewater discharge study on the Cooper River near Charleston, South Carolina.

Mixing Zone Study, Kill Van Kull, Bayonne, New Jersey. 2005-2006. Project manager and senior engineer for an industrial discharge study in a tidally-influenced coastal strait in New Jersey, to establish a mixing zone for arsenic.

Wastewater Discharge Evaluation, Napa River, Napa, California. 2005-2006. Project manager and senior engineer for a sanitary wastewater discharge study on the Napa River, a tributary to San Pablo Bay.

Consultation for Water Reuse at an Industrial Facility, Glen, Mississippi. 2005. Provided consultation regarding stormwater management to minimize discharge and support water reuse at a planned manufacturing facility in Glen, Mississippi. Also provided design recommendations for stormwater treatment.

Industrial Wastewater Discharge Evaluation, Amherst, Virginia. 2004-2005. Provided consultation to a manufacturing facility to address elevated copper concentrations in process discharge. Project involved monitoring and technical evaluations to support modification of permit limits for copper.

Preparation of a Wastewater Discharge Guidance Document for the American Petroleum Institute. 2004-2005. Primary author of a guidance document titled "Evaluation of Assimilative Capacity for Developing Water Quality-Based Effluent Limits for Petroleum Refinery Discharges".

Consultation on Mitigation of Industrial Wastewater Pond Odor Issues, West Virginia. 2003-2004. Provided technical evaluation of causes and recommendations for mitigation of odors from a wastewater pond receiving high BOD load.

Wastewater Discharge Evaluation, Willamette River, Salem, Oregon. 2003. Project manager and senior engineer for a mixing zone study involving municipal wastewater discharge to the Willamette River, to evaluate attainment potential for metals, ammonia and temperature.

Lake Study and Discharge Feasibility Analysis, Manistee Lake, Michigan. 2002-2003. Project manager and senior engineer for analysis of industrial wastewater discharge to the Manistee Lake. Project involved assessment of nutrient impacts to lake under various discharge location alternatives and phosphorus loading scenarios.

Stormwater Treatment Design, Kalamazoo, Michigan. 2002. Designed a full-scale batch treatment system for stormwater impacted by PCBs at a Superfund site in Kalamazoo, Michigan, to attain non-detect levels in surface water discharge.

Wastewater Discharge Evaluation, Spokane River, Washington. 2001-2002. Project manager and senior engineer for analysis of planned municipal wastewater discharge to the Spokane River, to evaluate attainment potential for metals, ammonia and temperature.

Wastewater Discharge Evaluation for Combined Sewer Overflow Discharges, Portland, Oregon. 2002-2003. Conducted technical analyses to develop permitting strategies for CSO discharges to the Willamette River, for attainment of copper water quality criteria.

Water Quality Study of Findley Lake, Ohio. 2002. Used existing data to simulate phosphorus cycling in lake, to evaluate potential alternatives for remediation of summer eutrophication.

Groundwater Quality Review, Portland, Oregon. 2002. Conducted a review of historical groundwater quality data in Portland Oregon to identify data suitable for establishing historical baseline conditions and for identifying groundwater quality trends.

Wastewater Discharge Evaluation, Willamette River, Wilsonville, Oregon. 2001. Project manager and senior engineer for analysis of municipal wastewater discharge to the Willamette River.

Consultation for Discharge from Quarry Dewatering Operation, Rockwood, Michigan. 2001. Advised client on regulatory constraints and technical concerns regarding discharge of dewatering effluent from quarry operations.

Consultation on Mitigation of Odors from a Stormwater Pond, Detroit Metropolitan Airport, Michigan. 2001. Developed technical alternatives and associated costs to oxygenate stormwater ponds receiving high BOD airfield runoff.

Stormwater Control Measures, C&D Technologies, Attica, Indiana. 2000-2001. Senior engineer for design of control structures for reducing stormwater flooding and sedimentation at an industrial facility. Performed hydrologic and hydraulic calculations, designed control structures, prepared drawings and construction specifications.

Development of Site-Specific Ammonia Limits for Blue Plains AWWTP, Potomac River, Washington, District of Columbia. 2001. Senior engineer for wastewater discharge analysis of municipal wastewater discharges to the Potomac River, District of Columbia. Developed seasonal criteria for ammonia, based on life stages of sensitive fish receptors. Applied mixing zone models to the tidal Potomac environment and reviewed results to support development of limits for the largest advanced wastewater treatment plant in the world.

Wastewater Discharge Evaluation, Tualatin River, Oregon. 1999-2000. Provided technical planning, direction and oversight, as well as project management, for mixing zone analysis of a proposed municipal wet weather overflow to the Tualatin River, near Portland, Oregon.

Water Quality Certification Study for Dredged Materials Disposal, Ashtabula, Ohio. 1999. Senior project engineer for preparation of Section 401 water quality certification for open water disposal of dredged sediments. Identified and conducted engineering evaluation of disposal alternatives.

Stream Study, Kalamazoo, Michigan. 1999. Provided technical planning, direction and oversight, and project management for a dry-weather monitoring study of Davis Creek in Kalamazoo, Michigan. Flow and water quality data were collected and analyzed under dry-weather (low-flow) conditions to evaluate potential impacts to the Creek by groundwater seepage from a municipal landfill.

Stormwater Pollution Prevention Plan, Rouge Steel Company, Dearborn, Michigan. 1999. Senior Project Engineer and Project Manager for preparation of the stormwater pollution prevention plan (SWPPP) for the 80-acre Rouge Steel Company facility in Dearborn, Michigan. Oversaw assessment of the facility's complex drainage system, which includes over 80 years of underground infrastructure.

Wastewater Discharge Evaluation, Crescent City, California. 1999. Provided technical planning, direction and oversight, as well as project management, for mixing zone analysis of a municipal wastewater discharge to the Pacific Ocean off the coast of northern California. Prepared project report detailing findings with respect to plume near-field dilution in compliance with the California Ocean Plan.

Wet Weather Overflow Discharge Feasibility Assessment, Fanno Creek, Oregon. 1999. Evaluated technical feasibility of a proposed wet weather overflow outfall to a tributary to the Tualatin River, using hydrologic, hydraulic, and mixing zone analyses. Provided technical planning, direction and oversight, project management, and project report preparation.

Stormwater Pollution Prevention Plan, Willow Run Airport, Ypsilanti, Michigan. 1999. Acted as Senior Project Engineer and Project Manager for preparation of the stormwater pollution prevention plan (SWPPP) for the Willow Run Airport in Ypsilanti, Michigan. SWPPP included coverage of all airport tenants.

Spill Plan Development, Trucking Terminal Facility, Ypsilanti, Michigan. 1998. Prepared a Spill Prevention, Control, and Countermeasures (SPCC) Plan for Federal compliance and a Pollution Incident Prevention Plan (PIPP) for State compliance, for a truck freight terminal in Ypsilanti, Michigan.

Lake Lanier Water Quality Modeling Study, Lake Lanier, Georgia. 1996-1998. Provided technical planning and oversight, as well as task management, for mixing zone analyses for a Corps of Engineers Reservoir in Georgia. Project conducted as part of a watershed and reservoir water quality assessment for regional water supply and wastewater treatment planning in northern Georgia.

Evaluation of Mixing Zone Models for Produced Water from Oil and Gas Operations in the Gulf of Mexico. 1993. Conducted mixing zone modeling and analysis for U.S. EPA Region 6, directed at evaluation of discharges of produced (high solids content) water from oil and gas operations in the Gulf of Mexico.

Water Quality Analysis and Modeling in Support of NPDES Requirements for the Expansion of the Lower Potomac Pollution Control Plant, Fairfax County, Virginia. 1992-1993. Conducted water quality modeling and analysis of toxic and conventional pollutant impacts from various proposed outfall extension scenarios. Analyzed ambient and mixing zone impacts.

Development of the User Friendly, PC-Based DYNTOX Probabilistic Toxics Model for Use in NPDES Development. 1992-1993. Provided technical assistance for update and improvement of DYNTOX.

Eutrophication Modeling of Providence River and Upper Narragansett Bay, Rhode Island, in Support of Dissolved Oxygen Restoration. 1992. Conducted water quality modeling for conventional pollutant impacts. Assisted in data analysis and prepared pre- and post-processing programs for the existing water quality model.

Analysis of Discharge Alternatives for West Rehoboth, Delaware in Support of Facilities Planning. 1992. Conducted mixing zone modeling and analysis for ocean discharge of municipal wastewater.

Environmental Remediation and Hazardous Waste Management

Site Investigation and Remediation Design, Former Keeler Brass Site, Kentwood, Michigan. 1994-2010 (ongoing). Project manager and lead engineer for investigation and remediation of groundwater impacts involving two separate plumes; one with hexavalent chromium and one with chlorinated VOCs.

Groundwater Investigation, Former Industrial Site, Arlington, Tennessee. 2007 – 2010 (ongoing). Project manager and senior engineer for investigation of volatile organic compounds in groundwater at a former industrial site.

Groundwater Investigation, Industrial Site, Rice Lake, Wisconsin. 2007 – 2009. Project manager and senior technical consultant for investigation of TCE in groundwater at an industrial site, to determine source and evaluate remedial alternatives.

Site Investigation, Industrial Site, Grand Rapids, Michigan. 2006 – 2008. Project manager and senior technical consultant for investigation of soil and groundwater impacts at an industrial site.

Consultation on Soil and Groundwater Contamination, Industrial Site, Montreal, Quebec. 2006. Providing review of site investigation and remedial activities related to soil and groundwater contamination at an industrial facility in Montreal, on behalf of a confidential industrial client.

Contaminated Sediment Investigation, Ottawa River, Toledo, Ohio. 2005-2006. Project manager and senior engineer for investigation of contaminated sediments in the Stickney Avenue Depositional Zone. Project involves sediment quality investigation and hydrodynamic modeling for remedial alternative analysis.

Remedial Investigation, Feasibility Study and Remedial Design for Soil and Groundwater Impacts, Fayette, Ohio. 1996-2006. Project manager and senior engineer for remedial investigation, feasibility study and design of interim remedial actions for soil and groundwater impacted with chlorinated solvents, including soil removal, groundwater collection and treatment, and relocation of municipal water supply wells.

RCRA Facility Investigation Workplan for a Solvent Treatment Recycle, Storage and Disposal Facility in Chicago, Illinois. 1993-2003. Planned and prepared RCRA Remedial Facility Investigation (RFI) Phase I work plan for submission to Illinois Environmental Protection Agency. Provided field investigation support and technical evaluations. Certified closure of facility under RCRA.

Investigation of Cyanide and Copper Contamination in Groundwater, Grand Rapids, Michigan. 2002. Planned and managed investigation of cyanide and copper impacts to groundwater, resulting from historical plating operations.

Abandoned Mine Lands Investigation, Owyhee Mountains, Idaho. 2001. Provided senior review and technical consultation in support of site investigations at abandoned hard rock mining sites in southwestern Idaho for the U.S. Corps of Engineers. Investigations included preliminary soil, rock, sediment and surface water sampling to evaluate acid mine drainage impacts to nearby streams.

Contaminated Sediment Investigation and Pre-Design Testing, White Lake, Michigan. 2001. Planned and conducted sediment sampling in support of remedial design for contaminated sediment removal in Tannery Bay, White Lake, Michigan. Provided planning and oversight of bench-scale treatability tests for dredged sediments to provide data for design of sediment dewatering and stabilization systems.

Consultation on Sources of Sediment Contamination, Portland Harbor, Oregon. 2001-2002. Provided site review, data analysis, fate and transport evaluation, and related consulting services to evaluate and define the role of upland soil and groundwater contamination as a potential source of offshore sediment contamination at two separate sites on the Portland Harbor.

Remediation of Contaminated Sediments, Black River, Michigan. 1999-2001. Project Manager and Senior Project Engineer for remediation of 25,000 cubic yards of river sediments impacted with chromium and PCBs. Led evaluation of remedial investigation data review. Currently preparing focused feasibility study and providing engineering design for site remediation and restoration.

Investigation of Contaminated Sediments, Stormwater Pond, Detroit Metropolitan Airport. 2000. Designed and implemented a sediment sampling program to support closure of a 5-acre stormwater detention pond at Detroit Metropolitan Airport.

Contaminated Sediments Feasibility Study, Pine River, Michigan. 1999. Prepared conceptual design for removal action and engineering cost estimates for a range of sediment removal scenarios, on behalf of a petroleum refiner. Work was conducted in support of negotiations between client and USEPA/USDOJ for a Supplemental Environmental Project.

Remediation of Petroleum-Impacted Soil and Groundwater, Utica, Michigan. 1999-2002. Conducted an engineering feasibility analysis to evaluate remedial alternatives for soil and groundwater impacted with gasoline constituents from a leaking gasoline UST. Designed and implemented selected remedy for groundwater, consisting of *in situ* bioremediation using oxygen enhancement.

Groundwater Remediation at a Superfund Site in Kalamazoo, Michigan. 1992-2000. Performed engineering evaluations/cost analysis (EE/CA) and prepared design documents for interim remedial action, consisting of groundwater extraction wells. Conducted complete feasibility study in accordance with CERCLA requirements and prepared feasibility study report.

Remediation of Soil and Groundwater Impacted with Chlorinated Solvents, South Bend, Indiana. 1994-2002. Conducted streamlined feasibility study for remediation of soil and groundwater impacted by chlorinated organic compounds at an Interim Status RCRA TSD. Prepared detailed design and specifications for a multi-well soil vapor extraction/air sparging system to clean up soil and groundwater impacts from leaking solvent USTs.

Expedited Site Remediation, Warren, Michigan. 1998. Served as Project Engineer and Project Manager to assist with an industrial property transfer in Warren, Michigan. Conducted site investigation to evaluate subsurface impacts by releases from aboveground chemical storage and from a leaking UST, followed by focused soil and free product removal, as part of an industrial property transfer. Achieved industrial closure for the property under Michigan State regulations.

Litigation Support Related to a Leaking Underground Storage Tank, Detroit, Michigan. 1997-1998. Case involved contention over the source underground petroleum free product and impacts to soil and groundwater, as well as cost of remediation. Fundamental question(s): What was the source of observed free product impacts and what are the future remediation costs? Performed fate and transport analyses, provided technical support, prepared remediation cost estimates to support technical expert. Acted as project manager. Worked for plaintiff's (UST owner) attorneys.

Site Closure Activities, Delphos, Ohio. 1999-2002. Project Manager for closure of an industrial property under Ohio's Voluntary Action Program. Prepared closure certification documents following investigation. Prepared detailed technical submittals on extent and distribution of impacts, fate and transport of subsurface chemicals, and risk assessment.

Remediation of Soil and Groundwater Impacted with Chlorinated Solvents, Indianapolis, Indiana. 1994-2002. Conducted pilot testing and designed a soil vapor extraction system for remediation of soil beneath a building at an Interim Status RCRA TSD. Managed system operation.

Remediation of Soil and Groundwater Impacted with Chlorinated Solvents and Waste Mineral Spirits at a RCRA TSD in Portage, Indiana. 1993-2002. Conducted soil vapor extraction pilot test and designed a multi-well soil vapor extraction/air sparge system for remediation of soil and groundwater impacts from leaking solvent USTs at an Interim Status RCRA TSD. Responsible for overall system design, as well as drawings and specifications.

Remediation of Perchloroethylene at an Interim Status RCRA TSD, Mason, Michigan. 1994-2002. Conducted SVE and vapor-phase activated carbon pilot testing to address PCE impacts to soil. Designed one stand-alone SVE system for soil impacts at a former stormwater retention basin. Designed expansion of a second SVE well into a multi-well SVE/air sparge system to replace an existing groundwater extraction system.

Soil Vapor Extraction System Operation and Maintenance for PCE Soil Contamination, Pontiac, Michigan. 1993-2002. Acted as Project Engineer and Manager for operation, maintenance, and monitoring of soil vapor extraction system. Prepared and submitted quarterly reports on system performance required by Michigan Air Use Permit. Designed a multi-well expansion of the system to address impacts at multiple depths.

Remediation of Acetone-Impacted Soil, Cadillac, Michigan. 1996. Responded to an accidental release of hundreds of gallons of acetone from an aboveground storage tank. Designed and installed a full-scale soil vapor extraction to address soil impacts.

Spill Response and Remediation at a RCRA Solvent Transfer Facility in Romulus, Michigan. 1993. Coordinated and supervised spill response and soil remediation. Prepared spill response report.

Evaluation of Remediation and Closure Alternatives for a Wastewater Treatment Lagoon. 1994-1995. Conducted remedial investigations and evaluated remedial alternatives for an abandoned wastewater lagoon at a truck stop in Michigan.

Expert Consultation for the Sturgis, Michigan Municipal Well Field Superfund Site. 1995. Performed engineering evaluation of expended past costs and proposed future remedial costs for a Superfund site in south central Michigan, in support of litigation. Fundamental question(s): Were the proposed costs for remediation and water supply replacement reasonable? Provided technical review of proposed remedial & water supply designs and reviewed cost estimates.

Litigation Support Related to a Groundwater Impacts at a Chemical Distribution Facility in Muskegon Heights, Michigan. 1994-1995. Case involved contention over the source and timing of subsurface chlorinated solvent impacts. Fundamental question(s): What was the source and timing of observed chlorinated solvent impacts in groundwater and did that source occur during the period of time during which the defendant provided insurance coverage for the facility? Provided research and technical analysis in support of expert witness. Worked for defendant's (insurance company) attorneys.

Remedial Action for Hazardous Soils Impacted with PCP at a Wood Treating Site in Hatfield, Arkansas. 1995. Prepared and implemented site management plan, which included on-site screening and remediation of hazardous soils contaminated with pentachlorophenol from wood-treating operations.

Remedial Investigation for a Metal Fabricator at the Conrail Yards Area Site in Grand Rapids, Michigan. 1992-1993. Assisted in preparation of the remedial investigation report for the site.

Evaluation of PCB Impacts and Remedial Alternatives for a Paper Industry in Kalamazoo, Michigan. 1992-1993. Conducted a geostatistical analysis of the spatial distribution of PCB impacts. Conducted data collection and analysis. Prepared NPDES stormwater permit application.

Remediation of Petroleum-Impacted Soil and Groundwater at a Truck Stop in Hartland, Michigan. 1994-1996. Conducted remedial investigations and feasibility studies to evaluate subsurface impacts from leaking underground storage tanks at a truck stop. Conducted soil vapor extraction pilot testing and preliminary remedial design for facility.

Site Investigation and Hoist Removal for Commercial Property in Detroit, Michigan. 1992-1993. Oversaw removal of petroleum-impacted soils. Drafted site closure report for submission to Michigan Department of Natural Resources.

Petroleum Remediation at a Commercial Property in Detroit, Michigan. 1992-1994. Conducted Phase I Environmental Site Assessment for the property. Oversaw removal of the petroleum-impacted soils, and conducted soil sampling to ascertain removal extent and to confirm completion of remediation. Prepared engineering specifications for clay fill and anti-seep collars for utility entries. Drafted UST closure report for submission to Michigan Department of Natural Resources.

Software Development to Predict Remediation Effectiveness and Environmental Compartment Partitioning. 1992. Developed theoretical model and tested computer model. Provided technical support to computer programming staff.

Miscellaneous Environmental Site Investigations. 1992-Present. Worked on more than 70 environmental site investigations from Phase I to Phase III, including those listed above. Projects involved contaminated soil, groundwater, surface water, and sediments. Constituents of concern include free product, heavy metals, petroleum and non-petroleum organic compounds, and PCBs.

Litigation Support Related to a Bulk Petroleum Facility, Port Huron, Michigan. 1995-1996. Case involved contention over the relative contributions of different sources of petroleum in the subsurface. Fundamental question(s): Did a documented petroleum release on an adjacent property contribute to observed and remediated soil impacts on subject property? Performed fate and transport analyses, provided technical support, and acted as project manager. Worked for plaintiff's (bulk storage facility owner) attorneys seeking recovery of partial remediation costs from adjacent property owner.

Evaluation of PCB-Impacted Soils for a Manufacturing Facility in Neenah, Wisconsin. 1992. Identified remedial alternatives and prepared cost estimates.

Miscellaneous Compliance

Closure of Hazardous Waste Management Units at Several Interim Status RCRA TSDs in Michigan and Indiana. 1993-2000. Acted as Project Engineer and Project Manager for closure of multiple hazardous waste management units (HWMUs), including container storage areas and tank farms, at eight different Interim Status RCRA TSD facilities. Sites were located in Mason, Pontiac, Saginaw, and Grand Rapids, Michigan, and in Fort Wayne, Indianapolis, South Bend, and Portage, Indiana. Closure activities included environmental sampling, structural decontamination and demolition, and remediation of soil and groundwater. Responsibilities included preparation of closure plans for regulatory review, design of closure activities, contractor procurement and oversight, inspection of closure performance, and preparation of closure certification reports. All closure activities resulted in regulatory agency approval.

NPDES Discharge Permit Support, Multiple Projects. 1992-1996. Provided engineering support to surface water discharge permit studies, including hydraulic and hydrologic analysis of receiving waters, stormwater runoff calculation, and mixing zone modeling.

Air Permit Evaluation for an Industrial Facility, Auburn Hills, Michigan. 1997. Evaluated applicability of State air permit regulations and prepared Clean Air Act Title V potential-to-emit calculations. Demonstrated that facility was exempt from State permit requirements and from Federal Title V permit requirements.

Compliance Reporting for Leaking Underground Storage Tank Sites, Multiple Locations. 1992-2000. Prepared or assisted in preparation of compliance reports for more than a dozen leaking underground storage tank sites, including site investigation reports and closure reports.

Specialized Training and Coursework

SWMM Stormwater Modeling Workshop, short course conducted by Computational Hydraulics International, Ann Arbor, Michigan. May 2007.

Morphology, Morphodynamics and Ecology of Low-Slope Sand-Bed Rivers, short course conducted by the National Center for Earth-Surface Dynamics, The Johns Hopkins University, Baltimore, Maryland. May 2006.

Dam Breach Analysis Using HEC-RAS, short course conducted by the American Society of Civil Engineers, Secaucus, New Jersey, May 2006.

Streambank Investigation, Stabilization, and Restoration, short course conducted by the American Society of Civil Engineers, Scottsdale, Arizona, February 2004.

Dredging Engineering, short course conducted by the Center for Dredging Studies, Department of Civil Engineering, Texas A&M University, College Station, Texas, January 2000.

Risk-Based Corrective Action, short course conducted by the American Society for Testing and Materials, Lansing, Michigan, April 1999.

Part 201 Cleanup Criteria Symposium, seminar conducted by the Michigan Department of Environmental Quality, Lansing, Michigan, November 1998.

Slope Stability and Stabilization Methods, short course conducted by the American Society of Civil Engineers, Chicago, Illinois, August 1998.

Emergency Action Plan Development, workshop presented by the Dam Safety Unit of the Michigan Department of Environmental Quality, Lansing, Michigan, April 1998.

The Waterloo In Situ Course: Technologies for Intrinsic and Semi-Passive In Situ Remediation of Groundwater, short course presented by the Waterloo Centre for Groundwater Research, Kitchener, Ontario, May 1997.

Aeration Technologies for Site Remediation, Environmental Education Enterprises (E^3) Short Course, St. Louis, Missouri, March 1994.

Probability, Statistics, and Geostatistics for Environmental Professionals, National Ground Water Association Short Course, Schaumburg, Illinois, August 1993.

Toxics Modeling Seminar, LimnoTech, Ann Arbor, Michigan, September 1992.

Technical Writing Seminar, The University of Michigan School of Engineering and LimnoTech, Ann Arbor, Michigan, 1992.

OSHA 40 Hour Health and Safety Training for Hazardous Waste Site Operations and Emergency Response as per *29 CFR 1910.12*, ATEC Associates, Inc., Novi, Michigan, December 1992.

OSHA 8 Hour Health and Safety Refreshers for Hazardous Waste Site Operations and Emergency Response as per *29 CFR 1910.120*, 1994-2008.

Professional Affiliations

American Society of Civil Engineers, 1989-Present

American Geophysical Union, 1991-Present

American Academy of Environmental Engineers, 1999-Present

Water Environment Federation, 2002-Present

Society of American Military Engineers, 2003-Present (Detroit Post Board of Directors 2003 - 2007)

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DATE: November 18, 2009 **TECHNICAL MEMORANDUM**

FROM: Scott Bell
Ryan O'Banion

PROJECT: CAWSHAB

TO: Tom Granato (MWRDGC)
Sam Dennison (MWRDGC)

CC: Jennifer Wasik (MWRDGC)
Doug Bradley (LimnoTech)
Tim Towey (LimnoTech)

SUBJECT: Classification & Regression Tree Analysis for Chicago Area Waterway System Habitat Evaluation and Improvement Study.

Introduction

Classification & Regression Tree (CART) Analysis is a statistical technique used to identify the relative importance of explanatory variables (i.e., habitat or dissolved oxygen (DO) variables in this analysis) for a given response variable (i.e., the combined fish metric in this analysis). This technique was suggested by the expert review panel as an alternative or as a supplement to the multiple linear regression analysis conducted by LimnoTech as part of the Chicago Area Waterway System (CAWS) Habitat Evaluation and Improvement Study and documented in the *CAWS Habitat Evaluation Report* (LimnoTech, 2009). Specifically, the expert review panel suggested that the technique can potentially be used in a "limiting factor analysis" to identify environmental variables (habitat or water quality) that are most limiting to fish in the CAWS.

CART Methodology

CART was originally proposed in the 1980s (Breiman et al., 1984) and has since been used for a number of ecological studies published in the technical literature (Kolar and Lodge, 2002; Magnuson et al., 1998; Rathert et al., 1996). It can be used for screening variables, assessing the adequacy of linear models, and summarizing large multivariate data sets (Qian, 2009). CART is a binary recursive partitioning method that splits individual predictor variables in a dataset into two homogeneous groups and continues doing so until further division is unfeasible (Qian, 2009).

CART is well suited for the analysis of complex ecological data because it does not assume linear relationships between response and explanatory variables and it can operate with missing values (De'ath and Fabricus, 2000). Other significant advantages include the following:

- CART is a non-parametric method and, therefore, does not require transformation of the variables into normal or near-normal distributions as is required for multiple linear regression.

- CART does not require that strongly correlated variables be screened out before conducting the analysis.
- The results of the CART analysis can be readily displayed graphically to convey the hierarchy of the selected variables.

CART can be used on its own as a "limiting factor analysis' or it can be used to select variables for linear models (Qian and Anderson, 1999). The most common display method is the use of a plot which resembles an upside down tree. Each division in the tree can be considered a node, with children branching off to the left and right. In regression trees, the CART model functions by identifying the split in all variables of a dataset that reduces deviance. Deviance is represented by the residual sum of squares associated with the observed and predicted mean of a model node. The split which maximizes the reduction in deviance is chosen as the first split in the model. This split algorithm picks the best split for each successive node, without consideration for the performance of the overall tree (Qian, 2009). As the tree grows with more splits, it becomes more complicated. Cross-validation error, a statistical measures of the model's predictive error, can be used to "prune" the tree to a more manageable and understandable model.

There are disadvantages to CART analysis, including the following:

- CART results are non-continuous. This means that CART shows a binary split in the data where the samples on each side of the split share a common quality relative to the variable selected, but the results cannot be used to predict the response variable in a continuous manner; in other words, no equation is produced as with linear regression.
- Each selected variable is statistically descriptive of only the branch on which the variable appears. The variable selected at the first split is descriptive of the entire data set, but each subsequent variable below that is only statistically descriptive of the data in its branch of the tree. Therefore, unlike multiple linear regression, CART does not result in one set of variables that are descriptive of (and can be identified as important to) the response variable across the entire system.
- CART results in the identification of a single variable at each node of the tree, but there may be competing variables that reduce deviance by only slightly less, but that may be more descriptive of the response variable.

Some of these points are illustrated in the discussion of the results, below.

Results

Because CART does not require screening out of strongly correlated variables, it was possible to conduct the analysis of the CAWS data with more variables than were used in the multiple linear regression analysis. For this analysis, LimnoTech started with the list of 66 habitat variables from the *Habitat Evaluation Report*. This list was reviewed and a number of variables were combined, as they were in the original analysis. Several variables were also eliminated because they are redundant with other variables. The result was the list of 40 habitat variables in Table 1. Dissolved oxygen variables were also used in the analysis, as listed in Table 2. CART analysis was first conducted with only habitat variables, then the analysis was repeated with a combined set of habitat and dissolved oxygen variables.

Table 1. Habitat Variables Used in CART Analysis.

Variable	Abbreviation
Number of aquatic vegetative types	AQ_VEG
Average velocity	AVG_VEL
Number of bank pocket areas	BANK_POC_AREA
% Hardpan, deep	BH_D
% Hardpan, shallow	BH_S
% Substrate fine gravel, coarse gravel, cobble, and boulder, deep	BIG_D
% Substrate fine gravel, coarse gravel, cobble, and boulder, shallow	BIG_S
Bank angle	BNK_ANGL
Percent of bank length composed of marinas or water	BNK_MARWA
Percent of bank length composed of natural vegetation	BNK_NAT
Percent of bank length composed of riprap	BNK_RIPRAP
Percent of bank length composed of concrete, granite, steel, or wood	BNK_WALL
Depth of fines, from District PHA	CAWS_DPTH_FNS
% Inorganic Sludge	CAWS_INSLG
% Organic Sludge	CAWS_ORSLG
% Plant debris	CAWS_PLDBR
Flashiness Index (ratio of 10% to 90% exceedance flows)	FLASH_IN
Length of overhanging banks	LENGTH_OVR
Number of manmade structures	MAN_Made_Struct
Maximum depth	MAX_DEP
Maximum velocity	MAX_VEL
Average macrophyte coverage	MCRPH_CO
Commercial tonnage passing reach	NAV_THRU
Number of instream cover types within area	NUM_COV
Number of NPDES Permitted Outfalls	NUM_SUM
Number of off channel bay areas	OFF_CH_BAY
% riparian vegetation	P_RIP_VEG
Predicted secchi depth from turbidity sample	P_SECCI
% of canopy over water in reach – field measured	PERC_COV_ALT
Distance to nearest upstream CSO pump station	PUMPSTA_D
50% exceedance flow	Q50
% Sand and Fines, deep	SAFN_D
% Sand and fines, shallow	SAFN_S
Cadmium concentration in sediment	SED_CD
Simultaneously extracted metals in sediment	SED_SEM
Total PCBs in sediment	SED_TOT_PCB
Wetted perimeter of channel	WET_PER
Stream width	WETWIDTH
Width-to-Depth Ratio	WW_DIV_D
Distance to nearest upstream wastewater treatment plant	WWTP_D

Table 2. Dissolved Oxygen Variables Used in CART Analysis.

Variable	Abbreviation
24-hour antecedent average DO	DO_24hr_AVG
24-hour antecedent minimum DO	DO_24hr_MIN
48-hour antecedent average DO	DO_48hr_AVG
48-hour antecedent average DO	DO_48hr_MIN
% time DO<5 mg/L from June through September	Jun.Sep_CDOM.5
% time DO<6 mg/L from June through September	Jun.Sep_CDOM.6

Like other statistically-based data mining methods, CART can produce results that contain variables beyond a statistically optimum number. This is analogous to multiple linear regression, in which the absolute r-squared can be increased by adding more variables to the regression, but the adjusted r-squared will start to decrease beyond the optimum number of variables. In CART analysis, the over-specification of variables is addressed by a technique called pruning.

The goal of pruning is to reduce the prediction error for a tree and ensure that it is the best predictive tree (De'ath and Fabricius, 2000). Two methods have been proposed for the selection of appropriate pruning levels, but both rely on the calculation of cross-validation error. Cross-validation error is a simulated calculation where the data are randomly subset into ten groups. One subset is set aside and trees are fitted to the other nine subsets (Qian, 2009). The fitted trees are then used to predict the response of the remaining subset. The error is then calculated from the observed and predicted values (De'ath and Fabricius, 2000).

Brieman et al. (1984) proposed the 1-Standard Error rule for pruning. A tree size is chosen that has an estimated error rate within one standard error of the minimum cross-validation error. Qian (2009) suggests looking at the cross-validation errors associated with an over-grown tree. Cross-validation error decreases until a certain number of splits in the tree, and then it begins to increase. This increase in predictive error suggests that the more complex tree may be a result of "fitting noise". The tree should therefore be pruned at the level of complexity which has the least cross-validation error. Both pruning methods are accepted and their choice is arbitrary. For these analyses, trees were pruned based on the smallest cross-validation error method. It should also be noted that since the cross-validation error is a simulation, the selection of pruning levels can change between iterations with a different random starting seed.

The CART results for the 40 habitat variables alone produced the tree depicted in Figure 1. This tree shows two variables after pruning: maximum channel depth and percent overhanging vegetation cover. While the original tree had more branches and nodes, pruning resulted in only two nodes and three branches that were statistically significant. When the CART analysis was performed with the six DO variables and 40 habitat variables together, the result was the tree depicted in Figure 2, which contains three nodes and six branches that are statistically significant.

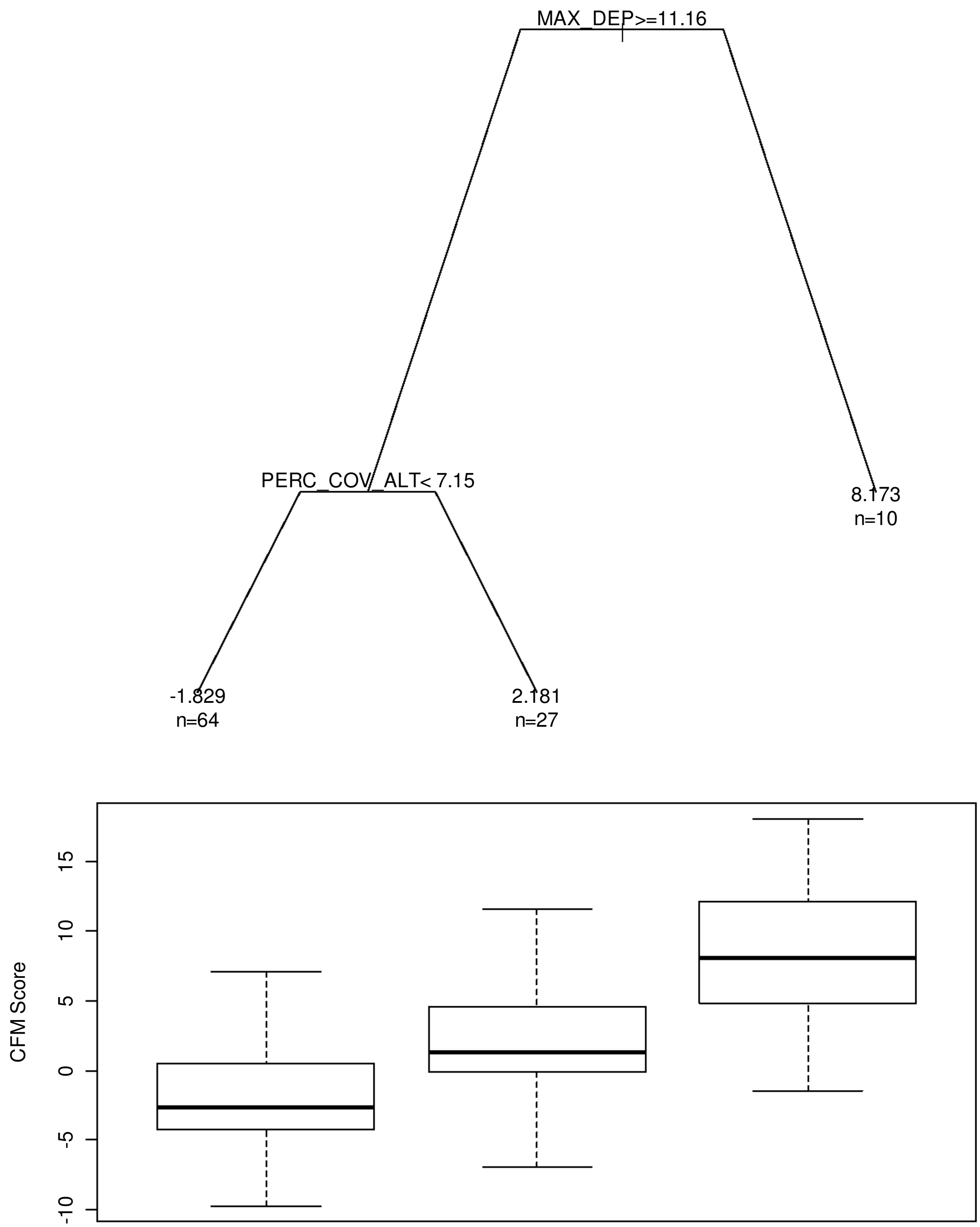

Figure 1. Regression Tree Resulting from CART Analysis of 40 Habitat Variables.

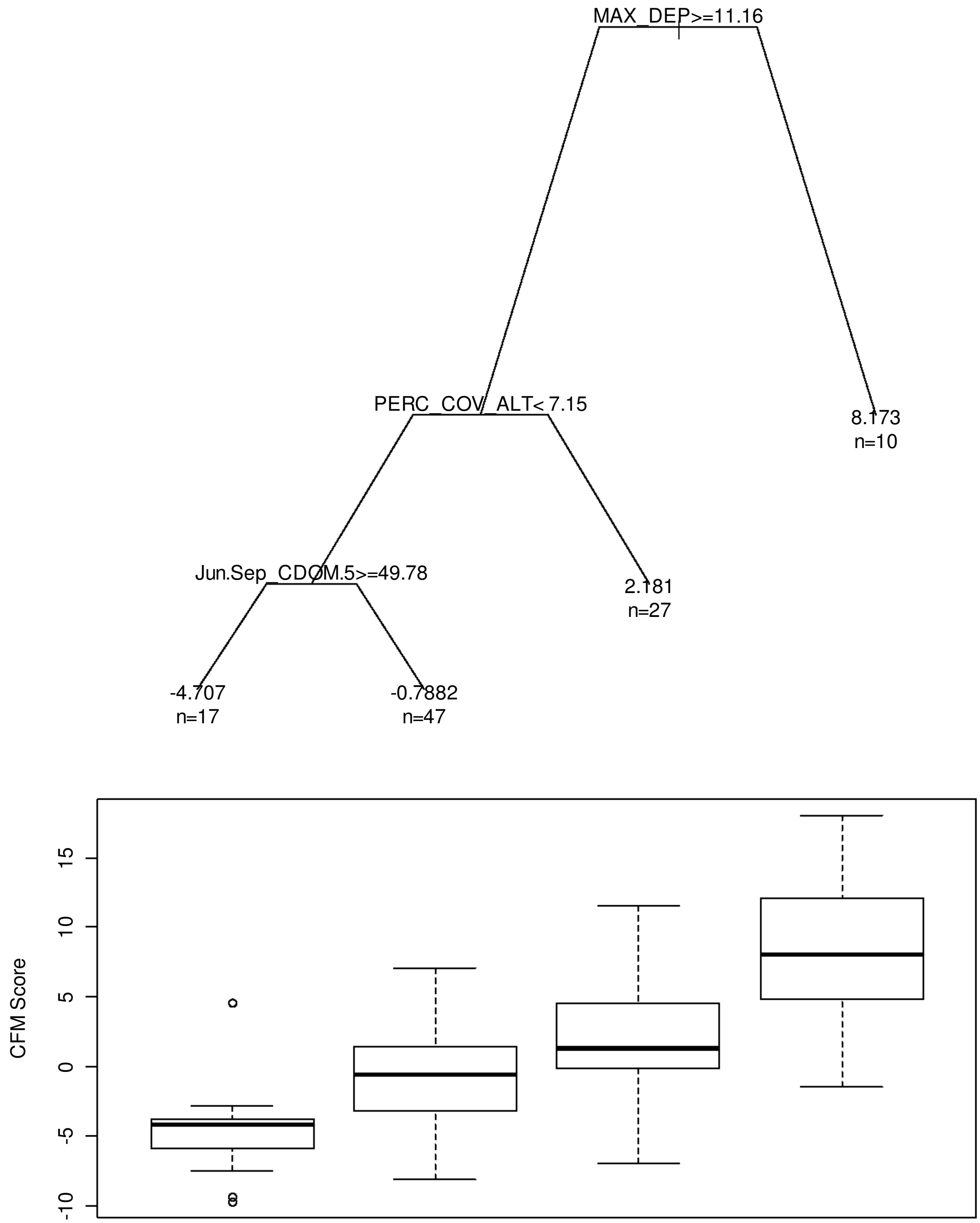

Figure 2. Regression Tree Resulting from CART Analysis of 40 Habitat Variables and Six Dissolved Oxygen Metrics.

The tree resulting from the CART analysis of habitat variables alone suggests that two of the 40 variables are the most important in describing the fish data from the CAWS: maximum channel depth and percent overhanging vegetation cover. Interestingly, one of these, maximum channel depth, also appeared in the final regression equation presented in the *Habitat Evaluation Report*. Percent overhanging vegetation cover did not appear in the final regression equation because it was screened out due to high inverse correlation with vertical bank walls (which did appear in the final regression).

The tree resulting from the CART analysis of habitat variables and DO metrics together yields the same two habitat variables as most important. Below these, percent of time DO was below 5 mg/L from June through September is included at the third node as statistically significant after pruning.

One important aspect of CART analysis is that it produces competing variables at each node. These are variables that yield comparable, but slightly less, deviance reduction than the selected variable at that node. It is important to consider these competing variables because they may be more important in understanding the data or the selected variables may be surrogates for some other competing variable. The competing variables for first split in the CART analysis with habitat and DO are listed in Table 3.

Table 3. Competing Variables for Selected Primary Split Variables in CART Tree of Habitat and DO.

Selected Variable	Competing Variables & Splits	Improvement
Maximum channel depth (improvement = 0.2597)	MCRPH_CO < 7.50 to the left	0.2095, (0 missing)
	SAFN_S < 30 to the left	0.2088, (0 missing)
	PERC_COV_ALT < 7.15 to the left	0.2047, (0 missing)
	CAWS_ORSLG < 0.5 to the right	0.1893, (0 missing)

Table 3 shows that macrophyte cover, shallow sand and fines, percent overhanging vegetation cover, and CAWS organic sludge could be used as the first split in the tree and there are no missing data for any of these variables. However, each yields a lower improvement (deviance reduction) than maximum channel depth. It is interesting to note that macrophyte cover appears as a competing variable and it was included in the final regression in the *Habitat Evaluation Report*. Percent sand and fines in shallow water appears as a competing variable, but is difficult to interpret. Above the split value presented (30%), the split separates the North Shore Channel, the Little Calumet River at Halstead Street, and the CSSC station at Bedford Park from the rest of the data. These are all very different reaches and it is likely that the differentiation may not be due to the presence of sand and fines, but to other factors. The presence of CAWS organic sludge as a competing variable for the first split provides support for its inclusion in the CAWS habitat index.

Conclusions

The CART analysis performed using CAWS habitat and DO data to describe the combined fish metric used in the *Habitat Evaluation Report* supports the following conclusions:

- CART analysis corroborates the finding of the multiple linear regression analysis that physical habitat is relatively more important than water quality to fish in the CAWS.
- The most important physical habitat variables identified by the CART analysis are maximum channel depth and percent overhanging vegetation cover. The former appeared in the final regression equation in the *Habitat Evaluation Report* and the latter is strongly inversely correlated with vertical bank walls, which also appeared in the final regression.
- The most important dissolved oxygen metric tested is the percent of time between June and September that DO is less than 5 mg/L, which is the same DO metric identified as being most important in the *Habitat Evaluation Report*.
- The occurrence of macrophyte cover and CAWS organic sludge as competing variables support their inclusion in the CAWS habitat index.

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MEMORANDUM

DATE: September 3, 2009

FROM: Scott Bell
Doug Bradley

PROJECT: Chicago Area Waterway System Habitat Evaluation and Improvement Study

TO: Project Files

CC:

SUBJECT: Evaluation of Applicability of Existing Habitat Indices to Chicago Area Waterway System.

Introduction

The Chicago Area Waterway System (CAWS) Habitat Evaluation and Improvement Study (the Study) involves development of system-specific habitat index that was developed by comparing habitat variables to a combined fish metric using multiple linear regression. This analysis resulted in a regression equation that included six key habitat variables and had an r-squared of 0.48 with the combined fish metric. Two other existing habitat indices were applied to the CAWS using data stations that were used in the Study. The pre-existing indices evaluated were the Qualitative Habitat Evaluation Index (QHEI) and the Michigan Non-Wadeable Habitat Index (MI-NWHI). The numeric index scores were then compared to the combined fish metrics for those stations using linear regression, as was done for the system-specific habitat index developed in the Study. The results of those comparisons are documented in this memo.

Qualitative Habitat Evaluation Index (QHEI)

The Qualitative Habitat Evaluation Index (QHEI) is a multi-metric index developed for characterizing habitat in Ohio streams (Rankin, 1989). The QHEI is composed of six variables: substrate, in-stream cover, channel morphology, riparian zone and bank erosion, pool/glide and riffle/run quality, and gradient. These variables are scored qualitatively, as the name suggests. The QHEI has proven to be a robust tool for qualitative assessment of natural streams in Ohio and has been widely applied elsewhere. The QHEI was recently applied to the CAWS as part of the Use Attainability Analysis (UAA) study conducted by the Illinois Environmental Protection Agency (Rankin, 2004). In that recent application, Rankin did not compare his scoring results to fish data.

As part of the Study, the QHEI was applied to 20 stations in the CAWS where fish data existed and where sufficient habitat data were available to develop a QHEI score. The results are presented in Table 1, along with the combined fish metric scores for these stations. The QHEI scores presented in Table 1 are graphically compared to their corresponding combined fish metric scores in Figure 1.

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Table 1. QHEI Scoring for CAWS Stations with Combined Fish Metric Scores.

Station	QHEI Score	CFM
AWQM 35 - Upper North Shore Channel (North of North Side WRP)	50	12.8
AWQM 36 - Lower North Shore Channel (South of North Side WRP)	51	11.5
AWQM 101 - Lower North Shore Channel (South of North Side WRP)	56	6.1
AWQM 73 - North Branch Chicago River South of Addison	41	0.1
AWQM 46 - North Branch Chicago River South of Addison	37	-2.5
AWQM 100 - Chicago River	34	2.2
AWQM 99 - Bubbly Creek	35	8.4
AWQM 40 - Chicago Sanitary and Ship Canal	45	4.2
AWQM 75 - Chicago Sanitary and Ship Canal	44	-1.1
AWQM 41 - Chicago Sanitary and Ship Canal	50	3.9
S1 - Chicago Sanitary and Ship Canal	42	0.6
S2 - Chicago Sanitary and Ship Canal	49	10.9
AWQM 48 - Chicago Sanitary and Ship Canal	37	4.6
AWQM 92 - Chicago Sanitary and Ship Canal	50	-3.7
S3 - Cal-Sag Channel	48	-2.7
S4 - Cal-Sag Channel	50	-5.2
S5 - Cal-Sag Channel	38	-3.3
AWQM 59 - Cal-Sag Channel	48	-8.1
AWQM 56 - Little Calumet River	45	1.4
AWQM 76 - Little Calumet River	47	1.0

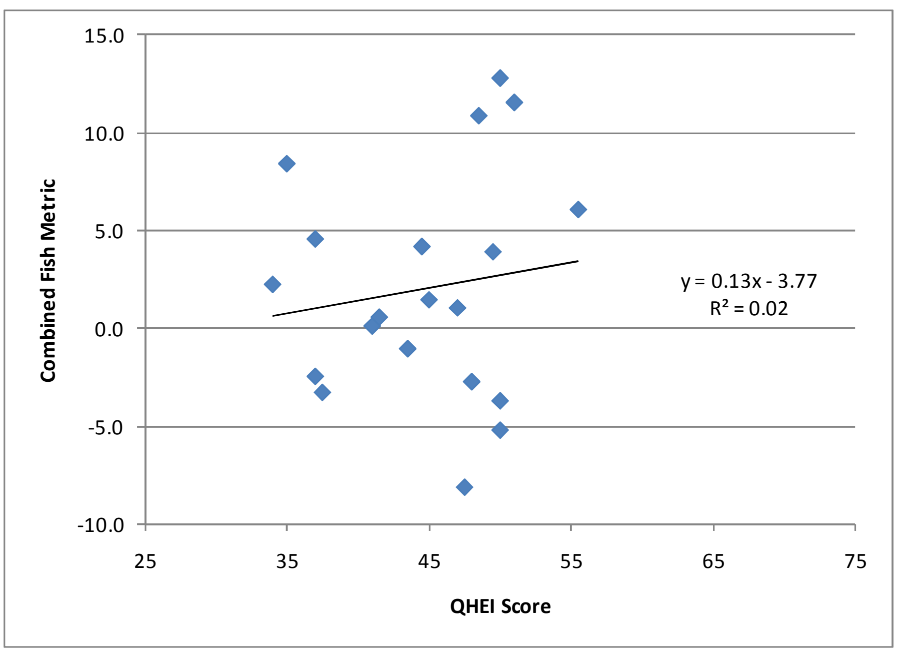

Figure 1. Linear Regression of QHEI Scores for CAWS Stations with Combined Fish Metrics.

Linear regression of these two sets of variables results in an r-squared value of 0.02. This indicates that the QHEI explains about 2% of the variability in fish data from the CAWS, for this data set. It is also worth noting that the QHEI results in a relatively narrow range of scores (34 to 56) for the CAWS stations, indicating that the QHEI may be limited in its ability to discern variability in physical habitat within the CAWS.

Michigan Non-Wadeable Habitat Index (MI-NWHI)

The Michigan Non-Wadeable Habitat Index is a multi-metric index developed for characterizing habitat in Michigan non-wadeable streams and rivers (Merritt et al., 2005; Wilhelm et al., 2005). Features used in the index include: riparian width, large woody debris, aquatic vegetation cover, sediment deposition, bank stability, substrate size, and off-channel habitat. The variables scored in the index are quantitatively measured. The index was developed using data from natural rivers in Michigan.

The MI-NWHI was applied to the same 20 stations as were used for the QHEI. The results are presented in Table 2, along with the combined fish metric scores for these stations. Figure 2 graphically depicts the MI-NWHI scores presented in Table 2 against their corresponding combined fish metric scores.

Table 2. MI-NWHI Scoring for CAWS Stations with Combined Fish Metric Scores.

Station	MI-NWHI Score	CFM
AWQM 35 - Upper North Shore Channel (North of North Side WRP)	39	12.8
AWQM 36 - Lower North Shore Channel (South of North Side WRP)	42	11.5
AWQM 101 - Lower North Shore Channel (South of North Side WRP)	39	6.1
AWQM 73 - North Branch Chicago River South of Addison	12	0.1
AWQM 46 - North Branch Chicago River South of Addison	2	-2.5
AWQM 100 - Chicago River	2	2.2
AWQM 99 - Bubbly Creek	14	8.4
AWQM 40 - Chicago Sanitary and Ship Canal	9	4.2
AWQM 75 - Chicago Sanitary and Ship Canal	23	-1.1
AWQM 41 - Chicago Sanitary and Ship Canal	32	3.9
S1 - Chicago Sanitary and Ship Canal	43	0.6
S2 - Chicago Sanitary and Ship Canal	25	10.9
AWQM 48 - Chicago Sanitary and Ship Canal	12	4.6
AWQM 92 - Chicago Sanitary and Ship Canal	26	-3.7
S3 - Cal-Sag Channel	33	-2.7
S4 - Cal-Sag Channel	27	-5.2
S5 - Cal-Sag Channel	22	-3.3
AWQM 59 - Cal-Sag Channel	29	-8.1
AWQM 56 - Little Calumet River	16	1.4
AWQM 76 - Little Calumet River	26	1.0

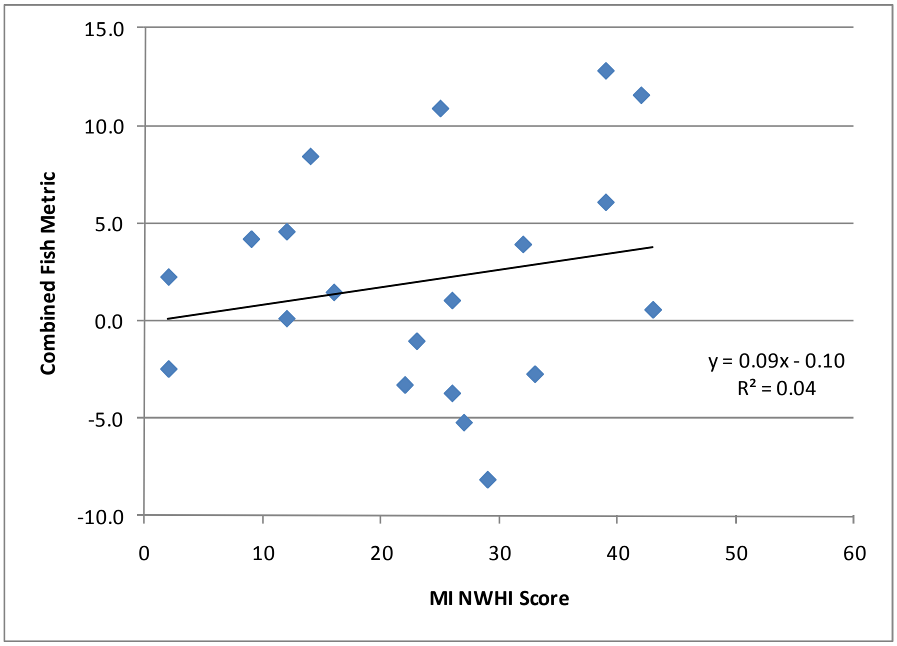

Figure 2. Linear Regression of MI-NWHI Scores for CAWS Stations with Combined Fish Metrics.

As shown in Figure 2, the r-squared for the linear regression of the MI-NWHI scores with the corresponding combined fish metric values is 0.04. This is slightly better than the QHEI, but it still indicates that the MI-NWHI explains only about 4% of the variability in fish data from the CAWS, for this data set.

Comparison of Other Indices to CAWS System-Specific Habitat Index

The analyses presented above demonstrate that these two pre-existing indices perform relatively poorly when compared to actual fish data from the CAWS. While not an exhaustive evaluation of existing habitat indices, this serves to underscore the uniqueness of the CAWS and the importance of using system-specific tools to evaluate habitat and fisheries in the CAWS. By comparison, the system-specific CAWS habitat index developed in the Study yielded an r-squared value of 0.48 compared to the combined fish metric. This result is vastly better than the result obtained with the QHEI and the MI-NWHI. This observation supports the conclusion that the CAWS habitat index developed in the Study is superior to existing indices for evaluating habitat in the CAWS.

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DATE: January 14, 2010 **TECHNICAL MEMORANDUM**

FROM: Tim Towey
Doug Bradley
Scott Bell

PROJECT: Chicago Area Waterways Habitat Evaluation and Improvement Study

TO: Tom Granato, Ph.D (Metropolitan Water Reclamation District of Greater Chicago)
Sam Dennison, Ph.D (Metropolitan Water Reclamation District of Greater Chicago)

CC: Jennifer Wasik (Metropolitan Water Reclamation District of Greater Chicago)

SUBJECT: Cluster Analysis of Fish Abundance Data in the CAWS.

Introduction

This memo documents statistical cluster analysis of fish abundance data from the Chicago Area Waterway System (CAWS) as a means to help describe the dominant fish community in the managed part of the CAWS. This work was completed as part of the CAWS Habitat Evaluation and Improvement Study, under contract to the Metropolitan Water Reclamation District of Greater Chicago (the District).

Cluster analysis is a multivariate statistical technique used to group similar observations or variables into discreet groups. Cluster analysis was applied to the fish abundance data collected in the CAWS to identify groups of fish species (communities) that tend to be found together. This analysis was undertaken to provide the Metropolitan Water Reclamation District of Greater Chicago (District) with information about the current fish communities that exist in the CAWS and to support decision-making related to the determination of appropriate biological endpoints (that is, target fish communities) for system management and habitat restoration efforts.

Data Description and Treatment

The District has been collecting fish data annually since 1974 (with the exception of 1981 and 1982) within the CAWS and surrounding area. In 2001, the District formalized their Ambient Water Quality Monitoring (AWQM) program for waterways managed by the District, which include the CAWS. For the purposes of this analysis, LimnoTech has limited the fish data analysis to the fish data collected between 2001 through 2008. During this period, the District has collected fish data at 43 stations within the CAWS. Twenty-six of these 43 stations are part of the District's AWQM program, including three locations outside of the managed area; six stations are located at the District's five Side Elevated Pool Aeration (SEPA) locations; three stations are sites of particular interest to the District on Bubbly Creek; three stations are supplemental sites sampled only in 2007[1]; and five stations are supplemental sites sampled only in 2008. The District collected fish data within the CAWS using boat electrofishing procedures following standard protocols.

Sixty-seven different species were collected at the 43 District monitoring stations between 2001 and 2008. For the purpose of this analysis, the species that were only observed during a single collection event were not included, leaving 50 species observed during 148 events.

Cluster Methodology

Hierarchical cluster analysis (HCA) was performed using the R statistical environment. HCA is an agglomerative clustering method, meaning that each variable, fish species in this case, begins as an independent cluster. The algorithm proceeds in a stepwise fashion, with the two most similar clusters merged at each step until all the variables are grouped into a single cluster. The determination of cluster similarity depends on two factors: the distance measurement method and the cluster linkage method. The distance measurement is the method used to measure distance between two points, while the linkage method determines between what points the cluster similarity criterion is applied.

For this analysis, the Bray-Curtis, or Sorenson, distance measurement was used. This is a commonly used distance measurement in ecological applications. The Bray-Curtis distance (d_{BC}) between species i and j for n observations is calculated as follows:

$$d_{BC}(i,j) = \frac{\sum_{k=1}^{n} |y_{i,k} - y_{j,k}|}{\sum_{k=1}^{n} (y_{i,k} + y_{j,k})}$$

where y is the number of fish collected at each observation (k).

Two candidate linkage methods were evaluated: complete linkage and Ward's linkage. Complete linkage merges clusters based on the distance between the furthest observations in the clusters, while Ward's linkage minimizes the intracluster sum-of-squares distance. Both of these linkage methods tend to produce multiple clusters with many members and relatively few clusters with only one or two members. However, in this case, the complete linkage method produced several clusters associated with a single species and one very large cluster that included nearly all of the species found in the CAWS. Ward's linkage produced clusters with several members, and was determined to be the better method for this application.

To determine the appropriate number of clusters to retain for further evaluation, a plot of the maximum cluster dissimilarity was plotted as a function of the number of clusters (Figure 1). Generally, a value in the range of the "knee-of-the-curve" is chosen as the appropriate number of clusters. The knee for this analysis occurs at, approximately, the six cluster level, suggesting that the six cluster model should be evaluated further. Results from a six-cluster analysis were evaluated and were determined to yield informative results.

[1] These three supplemental sites were all in the Cal-Sag Channel and were identified as Cal Sag – 104th, Cal Sag – Kedzie, and Cal Sag – SW Highway. In 2007, electro-fishing was performed at these three sites and the data from those samples were included in the analysis. Fyke net data were also collected from the Cal Sag – SW Highway site, but were not included in the analysis.

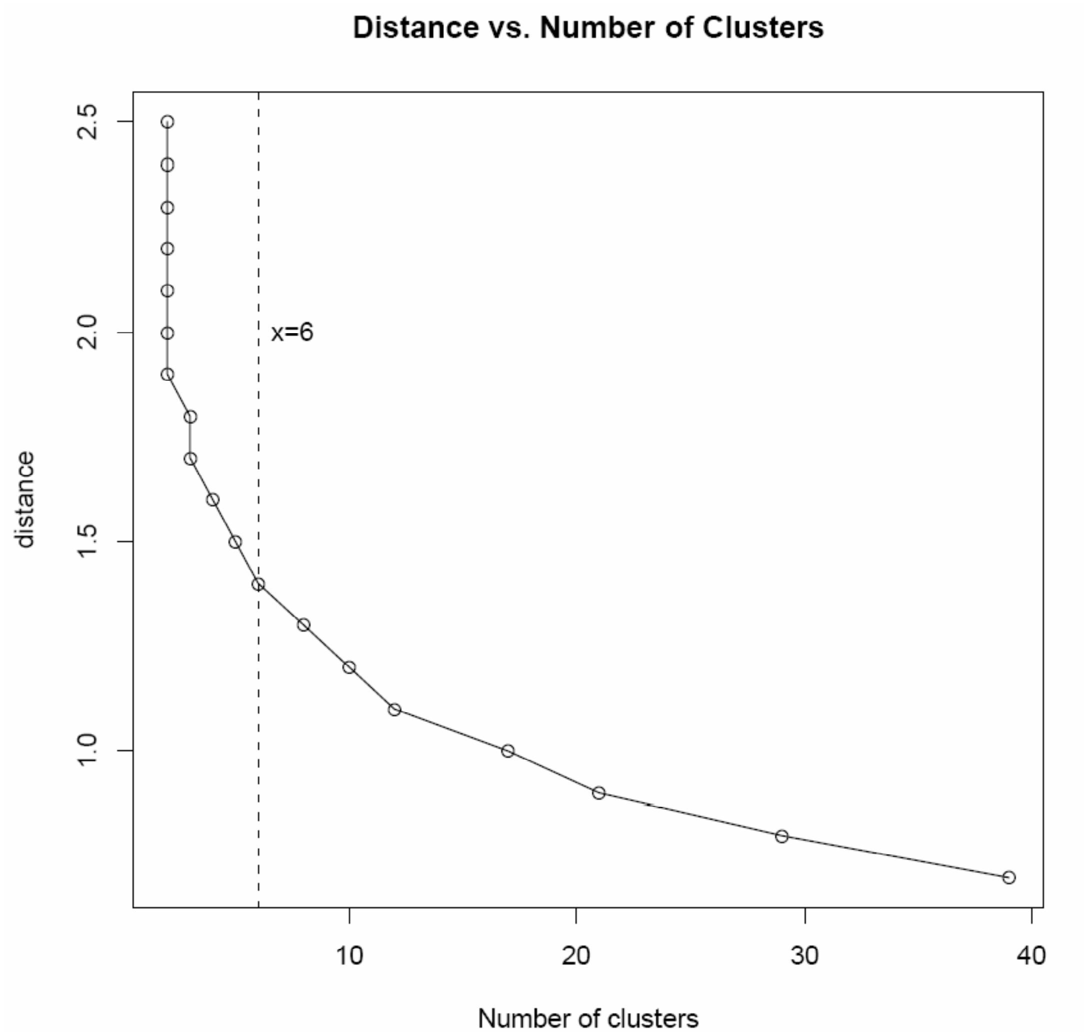

Figure 1. Plot of distance or dissimilarity as function of the number of clusters. The six cluster value was chosen as the approximate knee of the curve.

Results

The cluster analysis using six clusters produced several clusters with multiple species. A dendrogram showing the clusters is provided in Figure 2. The dendrogram shows the six clusters retained for further evaluation (bracketed in red) and the relationships between species within each cluster. The species that have the greatest tendency to occur together in the CAWS are bracketed furthest to the left.

Five of the six clusters include at least one species with a minimum count of 45 fish collected. The sixth cluster, which includes steelcolor shiner, only contains three species, none of which had more than 5 total fish observed. This cluster does not appear to represent an important community in the CAWS and was not included in the evaluations of fish traits and geographic distribution.

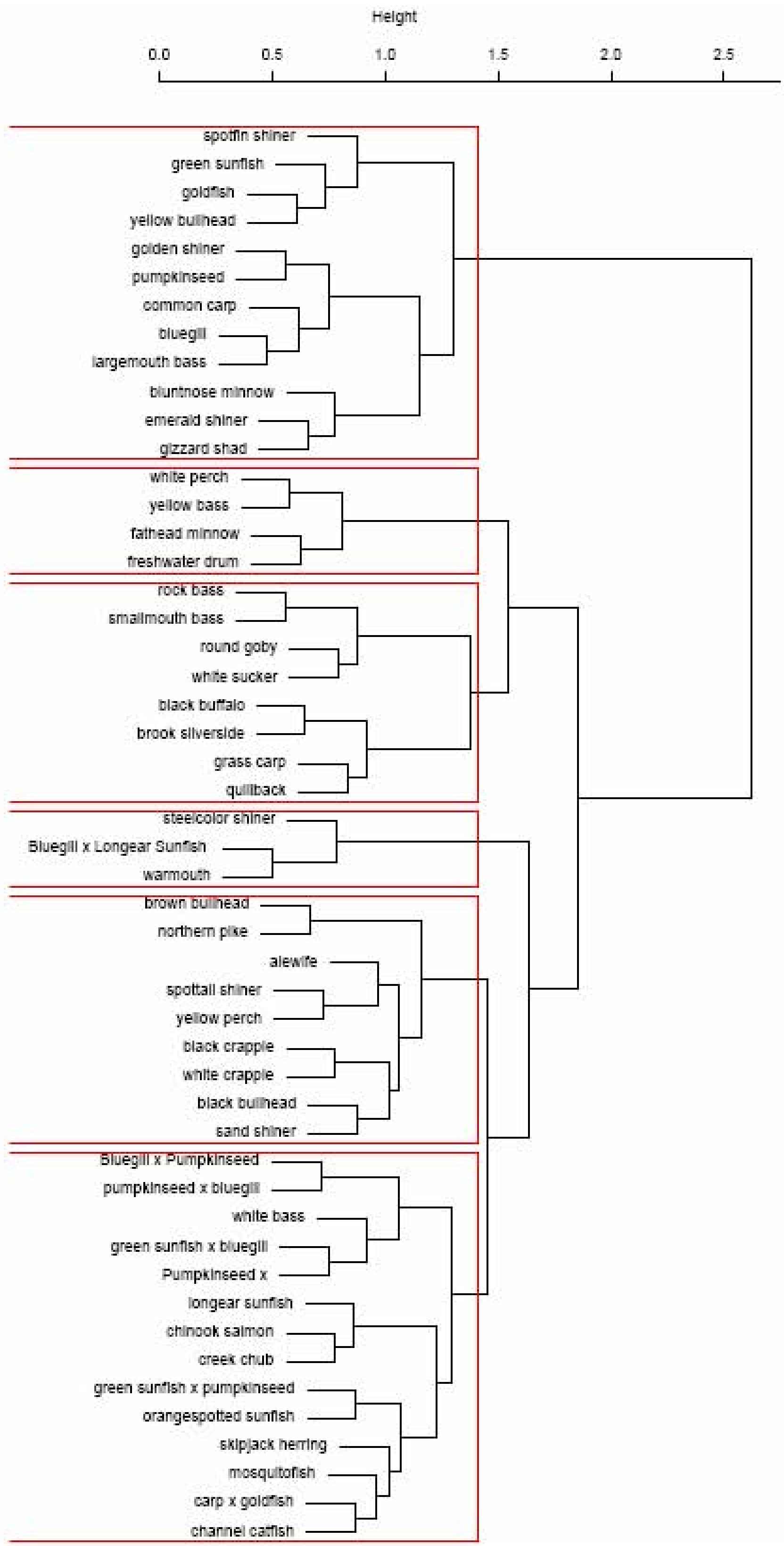

Figure 2. Dendrogram showing groupings of fish species found in the CAWS. The height axis represents a measure of dissimilarity. The groupings bracketed in red are the six clusters retained for further evaluation.

One cluster comprised the majority of the most abundant fish species, including largemouth bass, bluegill, common carp, and a number of minnow and sunfish species. This group was observed at every station in the CAWS. For this evaluation, that cluster will be referred to as the "dominant fish community." The remainder of the clusters will be referred to by the two most abundant species in that group.

Distribution of Traits within Clusters

The traits of the fish species in the clusters were evaluated using species trait data assembled from a variety of sources. Although no single source covered all species found within the CAWS, the majority of the trait data was derived from local sources. Where available, trait assignments were first established using state level data (IDNR 2000; 2008), then using data collected in the Midwest (Lyons et al., 2001), then using national level data (Meador and Carlisle, 2007), and finally using species-specific references where the relevant information was not available in the previously cited documents. The traits examined in this analysis include trophic level, substrate association, and parameters related to pollution tolerance.

Table 1 presents the percentage of total fish in each cluster that are associated with various trophic levels.

Table 1. Percentage of total fish collected in each cluster associated with various trophic levels. Many species are associated with more than one trophic level, so the percentages do not sum to 100%.

	Carnivore	Invertivore	Planktivore	Detritivore	Herbivore
Black crappie/Yellow perch	73%	90%	24%	3%	2%
Rock bass/Smallmouth bass	63%	66%	2%	22%	22%
Dominant community	15%	35%	14%	20%	47%
Channel catfish/Mosquitofish	36%	79%	1%	0%	0%
White perch/Yellow bass	90%	100%	0%	10%	0%

An evaluation of the distribution of the trophic levels (food chain links) represented within the clusters indicates that the dominant community has the most complete representation from all trophic levels, while other clusters primarily consist of fewer components of the food web. This suggests that the dominant community represents a relatively complete fish community, in the sense that its members occupy most trophic levels. The other clusters lack the components (such as prey base) to exist as independent communities.

Notably, the dominant community appears to contain trophic relationships found, or managed for, within other warm-water systems. For example, the strongest associations in this group appear between largemouth bass (a top predator) and bluegill (prey and omnivore), a commonly recommended combination of warm-water species found in angler management programs within lakes and reservoirs (Becker, 1983; Hayes et al., 1998). No formal fisheries management strategy has existed within the CAWS, so the community relationships are essentially self-regulated. Because of the unique characteristics of the CAWS, it is impossible to compare the existing, dominant community composition to a reference system or target community. However, recent work of Overman et al. (2009) posits that the trophic makeup of urban lake fisheries is commonly shaped by the forage fish component (gizzard shad and emerald shiner), and that these communities can differ among systems. This suggests that the current species composition within the CAWS may be appropriate for the limits of the system. The lack of fish management within the CAWS has resulted in a self-forming fish community that may be unique, but the community includes regionally important species and contains a general structure similar to natural lake systems.

The association of the various clusters with differing substrates was also examined to determine if substrate was a potential differentiating factor in the occurrence of the clusters. Table 2 presents the percentage of total fish in each cluster that are associated with various substrate types. The distribution of substrate types among the different groups suggests that the differentiation of the clusters may be, at least in part, due to habitat preferences found within the habitat-limited environment of the CAWS. In particular, the rock bass/smallmouth bass group consists primarily of fish that are associated with large substrates (boulder, cobble, and gravel), while most of the other fish in the CAWS tend to be associated with mud, sand, and vegetated substrates.

Table 2. Percentage of total fish collected in each cluster associated with various substrate types. Many species are associated with more than one substrate type, so the percentages do not sum to 100%.

	Boulder	Cobble/ Rubble	Gravel	Mud	Sand	Vegetated
Black crappie/Yellow perch	0%	15%	3%	52%	68%	49%
Rock bass/Smallmouth bass	39%	46%	85%	0%	0%	24%
Dominant community	0%	0%	9%	16%	30%	31%
Channel catfish/Mosquitofish	0%	34%	1%	26%	35%	16%
White perch/Yellow bass	0%	0%	0%	67%	10%	0%

The clusters were also evaluated with respect to their pollution tolerance. Meador and Carlisle (2007) conducted an extensive analysis of numerous fish species and their associations with a variety of physiochemical variables using data from the USGS National Water Quality Assessment Program. This effort resulted in a database of tolerance assignments for most fish species. Table 3 presents the percentage of total fish in each cluster that are classified as tolerant, moderately tolerant, and intolerant according to the Meador and Carlisle analysis.

Table 3. Percentage of total fish collected in each cluster classified according to their pollution tolerance.

	Tolerant	Moderately tolerant	Intolerant
Black crappie/Yellow perch	52%	33%	15%
Rock bass/Smallmouth bass	31%	2%	66%
Dominant community	89%	11%	0%
Channel catfish/Mosquitofish	98%	9%	4%
White perch/Yellow bass	81%	19%	0%

The distribution of pollution tolerances among the clusters indicates that all but one of the clusters are dominated by tolerant species. The exception to this is the rock bass/smallmouth bass cluster. The geographic distribution analysis discussed below and depicted in Figure 4 indicates that this may be due to proximity to Lake Michigan.

Geographic Distribution of Clusters

The geographic distribution of the clusters was evaluated to determine if there are differences among the CAWS reaches in terms of species composition. The fraction of the total number of individual fish collected that belong to each cluster was calculated for each fish collection event. The fractions were then averaged by station. Figure 3 (included at the end of this memorandum) shows a map with pie charts indicating the average composition at each sampling station. The figure shows that the dominant community makes up a large fraction of the fish observed at every station, with the exception of AWQM 49, which is located very close to Lake Michigan. This suggests that there are no locations on the CAWS that do not have the conditions to sustain this community. On average, this cluster represents 93% of the fish collected at each event.

However, because this cluster is found in such high proportions across the entire system, it is not particularly useful for differentiating between reaches, despite the fact that the dominant community cluster contains fishes considered regionally important (for example, largemouth bass, bluegill, gizzard shad and emerald shiner). Therefore, an additional map was generated using only the clusters outside of the dominant community to attempt to identify geographic differences within the CAWS. This map is included as Figure 4.

Figure 4 does illustrate some geographic trends of species abundance. The rock bass/ smallmouth bass group appears to occur in the highest proportions in areas where some water exchange with Lake Michigan occurs, such as: the North Shore Channel, the Chicago River, and the Calumet and Little Calumet Rivers in the vicinity of the O'Brien Lock and Controlling Works. The single exception to this trend is at one of the 2007 supplemental stations (LimnoTech ID 1092), where a single smallmouth bass was the only fish observed outside of the dominant community.

Other clusters also exhibit some geographic trends. The channel catfish/mosquitofish cluster tends to occur in higher proportion in the Chicago Sanitary and Ship Canal, while the white perch/yellow bass are most prevalent in the Cal-Sag Channel and the Little Calumet River. No clear geographic trend was observed for the black crappie/yellow perch group.

A final map is included as Figure 5 which is limited to the sampling stations with more than a single collection event. This map illustrates similar geographic trends as noted previously, however the trends appear more consistent among the reaches.

Conclusions

The hierarchical cluster analysis performed on the CAWS fish abundance data demonstrated that:

- There is a dominant fish community that occurs throughout the CAWS. This population includes species representing multiple trophic levels, an abundant and diverse prey base, and predator-prey relationships commonly observed in natural waterways within the region.

- The ubiquity of the dominant community suggests that the CAWS is supporting a viable, structurally complete, and regionally appropriate fish community under the existing, unmanaged conditions.
- The clusters outside of the dominant community generally consisted of fewer, less abundant species, and they did not comprise the same diversity of trophic levels. Additionally, these clusters occurred in conjunction with the dominant community, suggesting that these are not independent communities, but rather groups of species that occur with the dominant community under certain conditions.
- Some species traits and geographic trends associated with these clusters outside of the dominant community were observed, suggesting that habitat, water quality, or other factors may affect their occurrence.

This analysis was performed to help describe the current state of fish communities in the CAWS. Further investigation may be warranted to better understand the factors that relate to the occurrence of particular clusters or species outside of the dominant community. Additionally, further investigations would be needed to better understand certain aspects of the dominant community, including:

- the factors impacting the overall abundance of the group,
- the geographic distribution of the sub-clusters, and
- the conditions that promote desirable proportions of species within the community.

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