Technical Memorandum No. 3:

CHIRONOMID HEAD CAPSULE DEFORMITIES

CHICAGO AREA WATERWAY SYSTEM

HABITAT RESTORATION EVALUATION AND IMPROVEMENT STUDY

Prepared by

Baetis Environmental Services, Inc.

Chicago, Illinois

For

LimnoTech, Inc.

Ann Arbor, Michigan

In support of

Metropolitan Water Reclamation District of Greater Chicago

Chicago, Illinois

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Summary and Conclusion

A seven-year macroinvertebrate database was developed by the Metropolitan Water Reclamation District of Greater Chicago (District). The database includes the percent of head capsule deformities of larvae of the Chironomidae family (midges) of Dipera insects. Deformities in midge larvae head capsules have been frequently observed in contaminated sediments. Deformity is generally considered to be a sublethal, teratogenic response to contamination. Herein we summarize the data on chironomid larvae head capsule deformities at sampling stations throughout the Chicago Area Waterway System (CAWS).

Across all 177 samples of midge larvae head capsules that were examined, 10.9% were deformed (±2.8%). Mean rates of head capsule deformities ranged from none at Ambient Water Quality Monitoring (AWQM) Station 55 (Calumet River at 130th Street) to 30.2% at AWQM 100 (Chicago River at Wells Street). In an analysis of variance test, we concluded that there is no significant difference between mean rates of head capsule deformities for those collected on hester-dendy samplers and those collected in ponar dredge samples ($F=2.89$, $p=0.0911$).

We performed correlation analysis to examine the influence of sediment contaminants on head capsule deformities. Based upon Spearman correlation coefficients, the strengths of correlation were significant ($p<0.05$) in the hester-dendy samples for ammonia-N ($r=-0.399$), iron ($r=0.361$), and DDx (DDT + DDE + DDD) ($r=-0.396$). Spearman correlation coefficients were significant for the ponar samples for mercury ($r=0.659$), cadmium ($r=0.339$), copper ($r=0.439$), simultaneously extracted metals (SEM) ($r=0.455$), SEM-acid volatile sulfides ($r=0.454$), total PCB ($r=0.316$) and semi-volatile organic compounds ($r=0.323$). No contaminants displayed strong correlations for both collection methods. This may reflect differences in exposure routes or pathways for macroinvertebrates in ponar samples and hester-dendy samples.

Background

Morphological deformities in midge larvae have been frequently observed in contaminated sediments. Deformity formation is generally considered to be a sublethal, teratogenic response to contamination, and there is a large body of literature on midge head and mouthpart deformities. The results of these studies suggest a relationship between increased incidence of head capsule deformation with toxic stress, but substrate type, season, radioactivity, and genetic factors also contribute to the rate of deformation (Hamilton and Saether 1971; Jeyasingham and Ling 2000; Williams *et al.* 2001). Wiederholm (1984), studying Swedish lakes, found the occurrence of deformed mouth parts in recent and subfossil material of mostly Chironomus, Micropsectra and

Tanytarsus species increased from less than one percent of the larvae at unpolluted sites or time periods to approximately five to 25% at strongly polluted sites. Cushman (1984) studied larval *Chironomus decorus* in experimental ponds and found that head capsule deformations were significantly dose-related to a contaminant, but that the occurrence of deformities appeared to be a less sensitive measure of pollution than changes in abundance, biomass, number of taxa, and species diversity of benthic insects.

Under contract to LimnoTech, Inc., Baetis Environmental Services, Inc. (Baetis) has been retained to analyze macroinvertebrate data collected from the Chicago Area Waterway System (CAWS) between 2001 and 2007. The analysis supports the CAWS Habitat Evaluation and Improvement Study sponsored by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). This technical memorandum is intended to:

- Review the data characterizing head capsule deformities in representatives of the dipteran family Chironomidae, a group of non-biting midges
- Examine correlations of the rate of head capsule deformities with sediment contamination in the CAWS.

Methods and Materials

Macroinvertebrates were collected annually each summer from the CAWS from 2001-2007 by MWRDGC, with enumeration, identification and head capsule examination by EA Engineering, Science, and Technology, Inc. (EA) of Deerfield, IL. Figure 1 shows the locations of macroinvertebrate and sediment sampling stations. Macroinvertebrate collection methods included both hester-dendy sampler (artificial substrate) and a ponar (grab) sampler. Most macroinvertebrates were identified to genus; where possible species-level identifications were completed. A detailed description of the methodology is provided by EA in their 2006 report (EA 2006). LimnoTech, Inc. compiled EA's datasets, including head capsule deformities data, into one relational database for this project.

Descriptive and inferential statistics were derived for the 2001-2007 macroinvertebrate database using SAS software (Vers. 9.1, SAS Institute Inc. Cary, NC). In all cases, data were examined for normality using the Shapiro-Wilks test. Because very little of the macroinvertebrate abundance data are normally distributed, nor could they be transformed to approximate a normal distribution, we generally used nonparametric statistical methods, which are independent of the population distribution. Correlation analyses, for example, relied on Spearman correlation coefficients unless otherwise indicated. For all inference tests, conclusions have been based on a significance level, α, of 0.05.

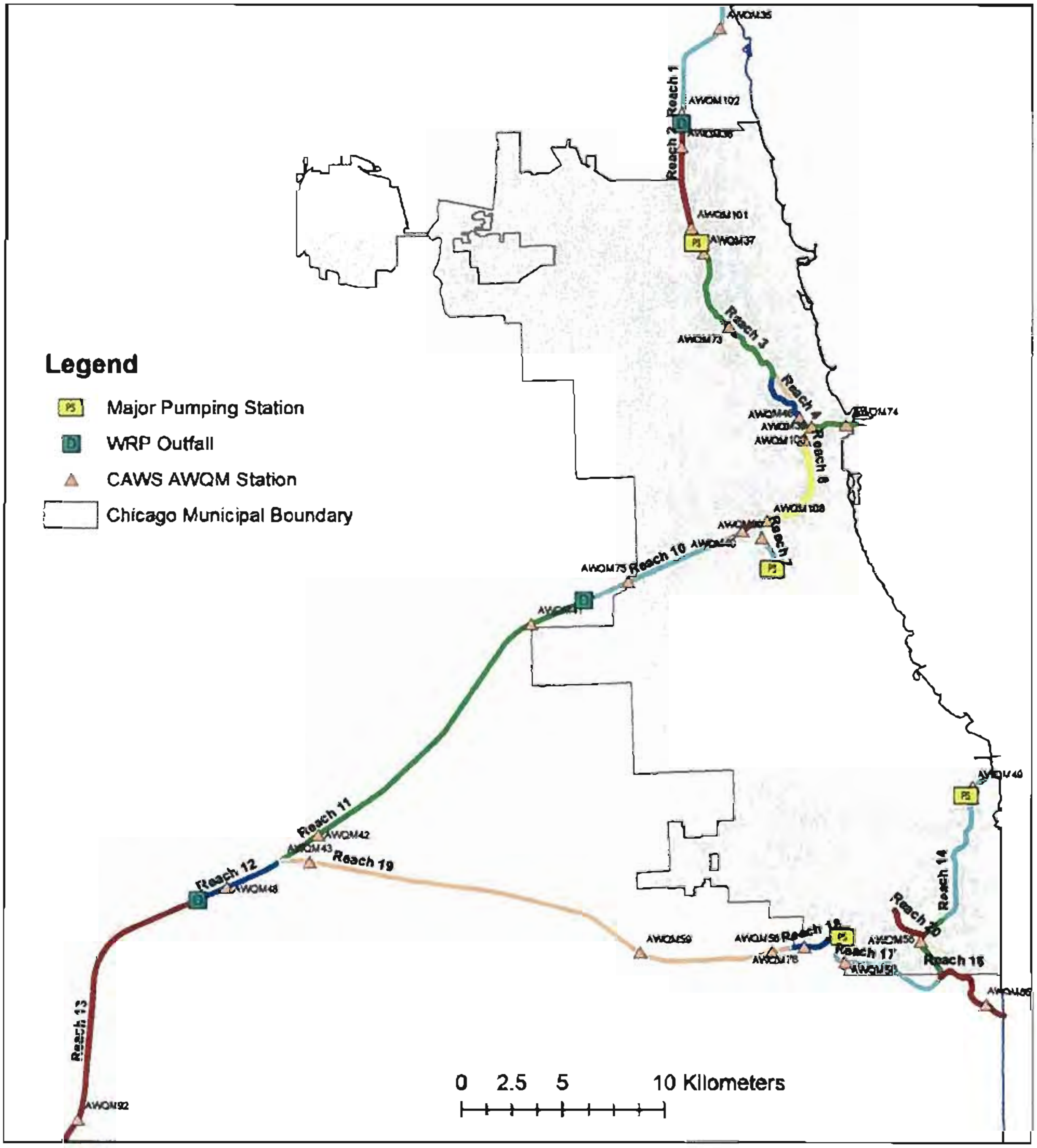

Figure 1. Locations of AWQM Stations in the Chicago Area Waterway System

Results and Discussion

From 2001 through 2007, EA examined 177 CAWS macroinvertebrate samples for chironomid head capsule deformities. Overall, head capsule deformities were observed in 10.9% of chironomid samples (±2.8%). Sampling statistics over the seven-year study period are given in Table 1. Mean rates of head capsule deformities ranged from none at Ambient Water Quality Monitoring (AWQM) Station 55 (Calumet River at 130th Street) to 30.2% at AWQM 100 (Chicago River at Wells Street).

Table 1

HEAD CAPSULE DEFORMITY STATISTICS

Station ID	N	Mean	Minimum	Maximum
AWQM 100	6	30.2	0	100
AWQM 101	3	7.0	0	13.3
AWQM 102	8	1.7	0	6.9
AWQM 108	6	9.8	0.66	27.3
AWQM 35	7	6.3	0	33.3
AWQM 36	12	3.3	0	16.7
AWQM 37	3	23.7	0	52.4
AWQM 39	4	4.1	0.6	14.3
AWQM 40	6	12.8	1.0	33.3
AWQM 41	15	19.3	0	100
AWQM 43	8	4.3	0.5	12.5
AWQM 46	12	23.3	0	100
AWQM 49	4	7.3	0.7	20.0
AWQM 55	2	0	0	0
AWQM 56	10	19.0	1.7	66.7
AWQM 58	4	7.8	0.4	15.0
AWQM 59	14	4.5	0	11.1
AWQM 73	6	8.0	0	40.0
AWQM 74	10	24.6	0	100
AWQM 75	8	3.0	0	6.9
AWQM 76	10	10.1	0	50.0
AWQM 92	15	4.0	0	16.7
AWQM 99	4	2.4	1.6	3.4

Macroinvertebrate samples were collected using two methods, the hester-dendy multi-plate sampler (HD) and the ponar dredge (PN). Table 2 displays the head capsule deformity statistics by collection method. There were 107 samples collected by the hester-dendy method that were examined for chironomid head capsule deformities; the mean rate was 8.9%. There were 70 samples collected using the ponar dredge and the mean rate of deformities was 13.9%. In an ANOVA (analysis of variance) test, we concluded that there is no significant difference between mean rates of head capsule deformities for the two collection techniques ($F=2.89$, $p=0.0911$).

Table 2

HEAD CAPSULE DEFORMITIES BY COLLECTION METHOD

Station ID	Method Code	N	Mean	Minimum	Maximum
AWQM100	HD	6	30.2167	0	100
AWQM101	PN	3	7.0333	0	13.3
AWQM102	HD	5	0.6600	0	1.8
AWQM102	PN	3	3.3667	0	6.9
AWQM108	HD	4	3.1700	0.7	4.9
AWQM108	PN	2	23.0100	18.8	27.3
AWQM35	HD	4	8.5750	0	33.3
AWQM35	PN	3	3.3667	0	8.7
AWQM36	HD	7	0.8800	0	2.8
AWQM36	PN	5	6.6520	0	16.7
AWQM37	PN	3	23.6667	0	52.4
AWQM39	HD	4	4.1000	0.6	14.3
AWQM40	HD	4	2.5875	1.0	3.9
AWQM40	PN	2	33.3300	33.3	33.3
AWQM41	HD	12	17.4042	0	100
AWQM41	PN	3	26.7833	0	42.8
AWQM43	HD	4	4.6550	0.5	12.5
AWQM43	PN	4	3.8150	1.1	6.7
AWQM46	HD	9	26.9444	0	100
AWQM46	PN	3	12.2200	0	20
AWQM49	HD	2	11.5600	3.1	20
AWQM49	PN	2	2.9750	0.7	5.3
AWQM55	HD	1	0.0000	0	0
AWQM55	PN	1	0.0000	0	0
AWQM56	HD	6	8.3650	1.7	20
AWQM56	PN	4	34.9225	3.0	66.7
AWQM58	HD	2	0.5000	0.4	0.6
AWQM58	PN	2	15.0000	15	15.0
AWQM59	HD	6	1.6000	0	4.8
AWQM59	PN	8	6.7600	0	11.1
AWQM73	HD	3	0.3667	0	0.6
AWQM73	PN	3	15.5667	0	40.0
AWQM74	HD	6	9.9550	0	25.0
AWQM74	PN	4	46.6650	16.7	100
AWQM75	HD	7	3.4143	0	6.9
AWQM75	PN	1	0.0000	0	0
AWQM76	HD	1	0.0000	0	0
AWQM76	PN	9	11.2144	0	50.0
AWQM92	HD	10	4.2570	0	16.7
AWQM92	PN	5	3.5580	0	9.1
AWQM99	HD	4	2.4175	1.6	3.4

During the examination of chironomids for head capsule deformities, EA recorded the lowest taxa. Unfortunately the taxa identifier was inconsistently recorded, so not all samples have taxa labels. Table 3 summarizes the chironomid taxa, by the method of their collection. Twelve taxa were identified and recorded from the hester-dendy samples. Six taxa were found in the ponar samples. One group, Chironomus sp., was found in sufficient numbers through both sampling methods, and, we found the Chironomus sp. data to be normally distributed. This allows for another ANOVA testing of equal means for the two methods, this test using a lowest taxa group. There were 7 Chironomus sp. samples collected using the hester-dendy technique and the mean rate of deformities was 34.3%. There were 10 Chironomus samples collected using the ponar dredge and the mean rate of deformities was 31.1%. Figure 1 is a box plot of the Chironomus sp. data. An ANOVA test found no significant difference between mean rates of Chironomus head capsule deformities for the two collection techniques (F=0.06, p=0.8055).

Table 3
LOWEST TAXA OF CHIRONOMIDS

Method Code	Lowest Taxa	N	Mean	Minimum	Maximum
HD	Chironomus	7	34.3	0	66.6
HD	Dicrotendipes fumidus	2	15.0	10.0	20.0
HD	Dicrotendipes lucifer	2	3.2	2.1	4.2
HD	Dicrotendipes modestus	3	0	0	0
HD	Dicrotendipes neomodestus	3	41.6	4.8	100
HD	Dicrotendipes simpsoni	17	2.4	0	6.6
HD	Glyptotendipes	4	3.7	0	12.5
HD	Nanocladius distinctus	1	9.1	9.1	9.1
HD	Parachironomus	2	23.8	14.3	33.3
HD	Procladius	1	0	0	0
HD	Procladius (Holotanypus)	1	20.0	20.0	20.0
HD	Xenochironomus xenolabis	1	100	100	100
PN	Chironomus	10	31.1	0	75.0
PN	Dicrotendipes lucifer	1	8.3	8.3	8.3
PN	Dicrotendipes modestus	1	11.1	11.1	11.1
PN	Dicrotendipes simpsoni	3	26.0	0.8	50.0
PN	Procladius	13	9.2	0	33.3
PN	Procladius (Holotanypus)	2	5.8	1.1	10.4

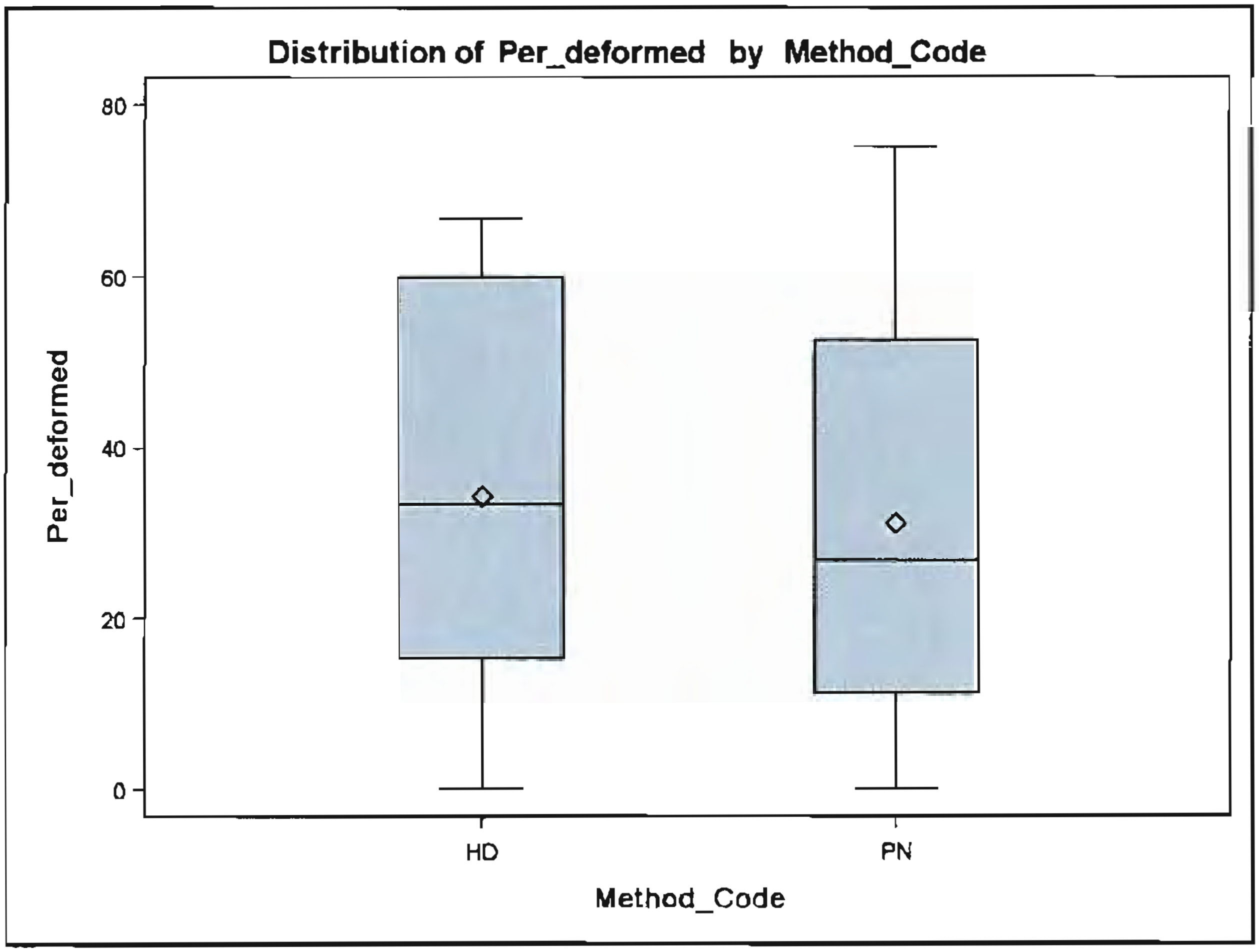

Figure 2. Box Plot of Chironomus sp. Head Capsule Deformities Rates, Grouped by Collection Method.

The Appendix is SAS output from the proc corr procedure and includes a correlation matrix between sediment contamination and the percent head capsule deformities in hester-dendy and ponar samples ($26 \leq N \leq 53$). Based upon Spearman correlation coefficients, the strengths of correlation were significant ($p<0.05$) in the hester-dendy samples for ammonia-N ($r=-0.399$), iron ($r=0.361$), and DDx (DDT + DDE + DDD) ($r=-0.396$). Spearman correlation coefficients were significant for the ponar samples for mercury ($r=0.659$), cadmium ($r=0.339$), copper ($r=0.439$), simultaneously extracted metals (SEM) ($r=0.455$), SEM-acid volatile sulfides ($r=0.454$), total PCB ($r=0.316$) and semi-volatile organic compounds ($r=0.323$). No contaminants displayed strong correlations for both collection methods. This may reflect differences in exposure routes or pathways for macroinvertebrates in ponar samples and hester-dendy samples.

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Appendix

SIMPLE STATISTICS AND CORRELATION ANALYSES FOR SEDIMENT CONTAMINANT CONCENTRATIONS AND CHIRONOMIDAE HEAD CAPSULE DEFORMATION

Correlation Analysis of % Head Capsule Deformities and Sediment Contamination, 2001-2007 1

By Station_ID and Year 07:57 Monday, February 23, 2009

The CORR Procedure

26 With Variables:	NH3_N Tot_Phos CN Hg Cd Cr Cu Fe Ni Pb Zn Hv_Mtls Ag As AVS SEM SEM_AVS gravel sand silt clay Heptachlor_epoxide Total_PCB DDx SVOC VOC
2 Variables:	HD_Per_deformed PN_Per_deformed

Simple Statistics						
Variable	**N**	**Mean**	**Std Dev**	**Median**	**Minimum**	**Maximum**
NH3_N	80	96.16916	176.16207	43.34971	1.29326	1400
Tot_Phos	81	2495	2841	1750	3.70000	19994
CN	82	1.95096	2.77954	0.87532	0	15.58542
Hg	82	0.85720	1.17186	0.48665	0	6.39700
Cd	82	6.65126	13.99237	3.49000	0.20000	121.87000
Cr	82	86.92561	77.91650	63.95000	12.80000	580.85000
Cu	82	150.05890	136.72495	101.55000	8.70000	825.40000
Fe	79	22919	9309	21727	3921	51809
Ni	82	39.14512	28.57443	30.24500	6.60000	204.60000
Pb	82	256.71061	230.46992	181.70000	21.36000	1255
Zn	82	563.46110	426.26106	484.26500	64.00000	2427
Hv_Mtls	82	1104	775.57662	951.36725	171.04300	4628
Ag	79	2.55354	5.08267	0.74500	0	34.80000
As	81	1.51358	2.15770	0.50000	0	10.30000
AVS	63	26.30032	42.10495	8.66000	0.24000	273.40000
SEM	65	54.19267	169.83660	10.20000	0.18000	1030
SEM_AVS	59	4.87216	12.43565	0.80679	0.01363	88.79310
gravel	64	3.95313	6.67713	1.00000	0	35.80000
sand	64	64.06875	23.43388	70.00000	7.40000	97.80000
silt	64	22.55312	17.21450	20.70000	0	63.00000
clay	64	9.41094	10.19695	4.95000	0.80000	48.00000
Heptachlor_epoxide	82	6.93639	5.41567	5.36776	2.00000	36.00000
Total_PCB	82	1763	2664	749.00000	5.37866	13722
DDx	82	143.26389	166.20820	103.67282	9.52744	1095
SVOC	78	159341	497970	53291	2868	3652353
VOC	81	150.84256	886.52013	39.96004	21.51463	8020
HD_Per_deformed	74	7.61331	10.96338	3.90000	0	56.53333
PN_Per_deformed	55	14.58059	15.44069	7.03333	0	60.00000

The CORR Procedure

Pearson Correlation Coefficients Prob > |r| under H0: Rho=0 Number of Observations	HD_Per_deformed	PN_Per_deformed
NH3_N	-0.24142 0.0816 53	0.03515 0.8340 38
Tot_Phos	-0.15525 0.2718 52	-0.02509 0.8811 38
CN	-0.13891 0.3212 53	-0.07480 0.6554 38
Hg	0.06281 0.6550 53	0.39290 0.0147 38
Cd	0.10557 0.4519 53	0.16073 0.3350 38
Cr	0.16002 0.2524 53	0.12053 0.4710 38
Cu	0.20516 0.1406 53	0.51139 0.0010 38
Fe	0.22335 0.1079 53	-0.25561 0.1214 38
Ni	0.27805 0.0438 53	0.31248 0.0561 38
Pb	0.32453 0.0177 53	0.25282 0.1257 38
Zn	-0.02060 0.8836 53	-0.01367 0.9351 38
Hv_Mtls	0.19018 0.1726 53	0.14445 0.3869 38
Ag	-0.05779 0.6810 53	0.09043 0.5892 38
As	0.00589 0.9666 53	-0.09038 0.5894 38
AVS	-0.18526 0.2177 46	-0.24213 0.2237 27

The CORR Procedure

Pearson Correlation Coefficients Prob > |r| under H0: Rho=0 Number of Observations	HD_Per_deformed	PN_Per_deformed
SEM	0.03160 0.8330 47	0.25169 0.1964 28
SEM_AVS	-0.02316 0.8828 43	0.34413 0.0852 26
gravel	-0.06253 0.6763 47	-0.10294 0.6022 28
sand	0.03897 0.7948 47	0.05337 0.7874 28
silt	-0.12267 0.4114 47	-0.08985 0.6493 28
clay	0.15072 0.3119 47	0.08766 0.6574 28
Heptachlor_epoxide	-0.04874 0.7289 53	0.05794 0.7225 40
Total_PCB	0.16859 0.2275 53	0.11309 0.4872 40
DDx	-0.19253 0.1672 53	-0.00505 0.9753 40
SVOC	0.26487 0.0553 53	-0.01296 0.9385 38
VOC	-0.17874 0.2003 53	-0.07384 0.6507 40

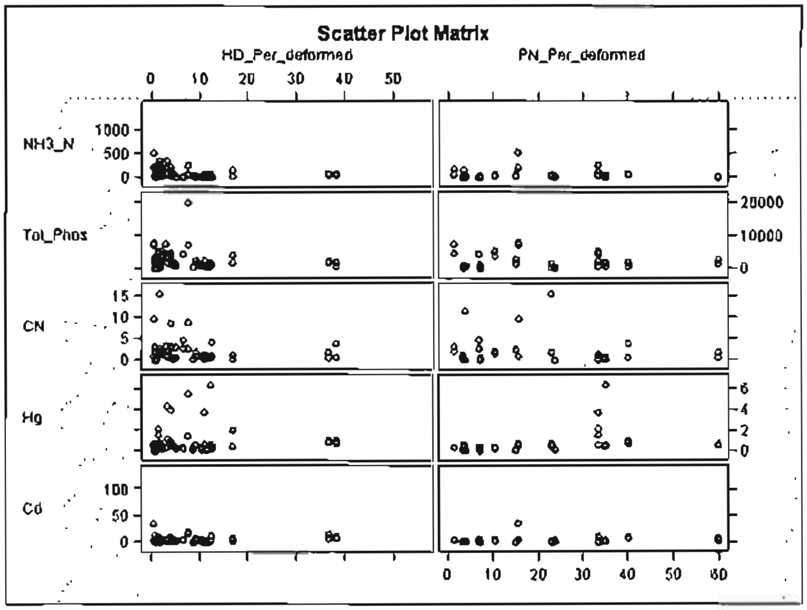
The CORR Procedure

Spearman Correlation Coefficients Prob > |r| under H0: Rho=0 Number of Observations	HD_Per_deformed	PN_Per_deformed
NH3_N	-0.39857 0.0031 53	0.19067 0.2515 38
Tot_Phos	-0.20595 0.1430 52	0.22574 0.1730 38
CN	-0.15316 0.2736 53	0.06071 0.7173 38
Hg	0.19060 0.1716 53	0.65907 <.0001 38
Cd	0.02178 0.8770 53	0.33892 0.0374 38
Cr	0.11819 0.3993 53	0.12077 0.4701 38
Cu	0.08475 0.5463 53	0.42869 0.0072 38
Fe	0.36146 0.0078 53	-0.26475 0.1082 38
Ni	0.13759 0.3259 53	0.27725 0.0920 38
Pb	0.06337 0.6521 53	0.25314 0.1252 38
Zn	-0.05897 0.6749 53	0.13720 0.4114 38
Hv_Mtls	0.07587 0.5892 53	0.20887 0.2082 38
Ag	-0.25105 0.0698 53	0.18532 0.2653 38
As	-0.05396 0.7012 53	0.01897 0.9100 38
AVS	-0.00426 0.9776 46	-0.27754 0.1610 27

The CORR Procedure

Spearman Correlation Coefficients Prob > |r| under H0: Rho=0 Number of Observations	HD_Per_deformed	PN_Per_deformed
SEM	0.21117 0.1542 47	0.45512 0.0150 28
SEM_AVS	0.22775 0.1419 43	0.45416 0.0198 26
gravel	0.17874 0.2293 47	0.15412 0.4336 28
sand	0.08875 0.5530 47	0.19327 0.3244 28
silt	-0.13372 0.3702 47	-0.11862 0.5477 28
clay	0.16272 0.2745 47	-0.06595 0.7388 28
Heptachlor_epoxide	-0.21028 0.1307 53	0.09130 0.5753 40
Total_PCB	0.17543 0.2090 53	0.31599 0.0470 40
DDx	-0.39639 0.0033 53	0.09506 0.5596 40
SVOC	-0.18769 0.1784 53	0.32305 0.0479 38
VOC	-0.18967 0.1738 53	-0.03607 0.8251 40

The CORR Procedure



APPENDIX C:

ANALYSIS OF THE RELATIONSHIP BETWEEN FISH AND WATER QUALITY IN THE CAWS

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Analysis of the Relationship Between Fish and Water Quality

in the Chicago Area Waterways System

December 8, 2009

Prepared for:

The Metropolitan Water Reclamation District of Greater Chicago

LimnoTech
Water | Environment | Scientists | Engineers

Ann Arbor, Michigan
www.limno.com

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1. INTRODUCTION

This report presents the findings of a comparative analysis of fish and water quality data in the Chicago Area Waterway System (CAWS). LimnoTech conducted this work as part of the Habitat Evaluation and Improvement Study currently underway to develop a clearer understanding of the environmental factors that affect fisheries in the CAWS, on behalf of the Metropolitan Water Reclamation District of Greater Chicago (the District).

1.1 OBJECTIVES

The CAWS Habitat Evaluation and Improvement Study is designed to identify the physical habitat factors that are most limiting to aquatic life (as represented by fish) in the CAWS and what potential exists for improvement. It is recognized, however, that water quality also plays a critical role in the health of aquatic ecosystems, so it is important to understand the relationship between fish and water quality in the CAWS in order to fully understand the conditions that favor or limit fish. Furthermore, the regulation of water quality through the Clean Water Act remains the only enforceable means that regulatory agencies have for improving the health of surface waters, so an understanding of the relationship between water quality standards attainment and fish success is important.

This analysis was undertaken to answer the following question: what changes, if any, can be expected solely from an improvement in water quality in the CAWS, if current uses and physical habitat conditions remain unchanged? In the analysis presented herein, this larger question was addressed by investigating four more focused questions:

- Do the data suggest a correlation between fish metrics and attainment of current water quality standards?
- Do the data suggest a response between fish metrics and attainment of proposed water quality standards?
- Are there correlations between fish metrics and other measures of dissolved oxygen?
- Are there other fisheries responses indicated by water quality metrics other than dissolved oxygen?

To answer these questions, comparative analyses of fish and water quality metrics were performed. The data used for these analyses are described below.

1.2 FOCUS ON DISSOLVED OXYGEN

It will be noted that the focus of the analyses presented in this report is on dissolved oxygen. There are several reasons for this:

- **Dissolved oxygen is critical to fish.** It well known that dissolved oxygen is a critical water quality constituent to support healthy fish populations. Low dissolved oxygen can create chronic health impacts on fish and severe depletion can cause fish kills. Therefore, an evaluation of fish and water quality would be incomplete without addressing dissolved oxygen.

- **Dissolved oxygen has been a long-standing issue in the CAWS.** There has been a history of dissolved oxygen depletion due to pollutant loading to the CAWS and the issue has been studied in the CAWS for decades. It was partly in response to these dissolved oxygen issues in the CAWS that the District established their continuous dissolved oxygen monitoring program and invested research, engineering, and construction resources in developing and building the sidestream elevated pool aeration (SEPA) stations that now exist in the CAWS.

- **A rich dissolved oxygen dataset is available for the CAWS.** As discussed below, the District has been collecting continuous dissolved oxygen data in the CAWS for several years. These data allow dissolved oxygen to be parameterized in a variety of ways not possible with event sampling data.

- **Dissolved oxygen has been the focus of recent proposed changes to water quality standards.** The Illinois Environmental Protection Agency (IEPA) has recently proposed changes to the water quality standards for the CAWS, and these proposed changes focus on dissolved oxygen.

For these reasons, an emphasis on dissolved oxygen is warranted in the analysis. In addition to dissolved oxygen, other water quality parameters were considered, evaluated and are discussed in the following section. However, the importance of dissolved oxygen and the availability of continuous data make it the focal point of this analysis.

1.3 DATA

The data used in this analysis consisted of water quality and fish data collected by the Metropolitan Water Reclamation District of Greater Chicago between 2001 and 2007. Details of these data are presented below.

1.3.1 Water Quality Data and Parameter Selection

The District's water quality data collection program in the CAWS includes continuous monitoring of certain parameters from several locations in the CAWS, as well as discrete sampling of water quality as part of their annual water quality monitoring program. These data collection programs are summarized below.

Continuous Monitoring

The District currently deploys continuous dissolved oxygen monitors at dozens of locations throughout the CAWS and in Chicago area wadeable streams. These monitors collect hourly dissolved oxygen readings and are serviced on a weekly schedule. A detailed discussion of the continuous dissolved oxygen monitoring (CDOM) program is represented in Minarik et al. (2008). For the analysis discussed in this report, CDOM data from 23 stations in the CAWS, collected between 2001 and 2007 were used. The locations of these CDOM stations are shown in Figure 1-1.

In addition to dissolved oxygen data, the District's CDOM program also collects continuous data on specific conductance, pH, and temperature. The data for these other parameters were reviewed to determine whether they should be included in this analysis. Specific conductivity was not included in this analysis because it is not regulated by water quality standards. pH data are limited in the CAWS, but review of available data show that all measurements are within the range of applicable water quality standards (*i.e.*, between 6.5 and 9.0), therefore pH was not included in this analysis.

Temperature data collected in the CDOM program between 2001 and 2007 were reviewed to determine whether temperature should be included in this analysis, which showed that temperature conditions in the CAWS during this time might have exceeded the proposed water quality standards for temperature. Based on this review, temperature was included in this analysis.

Annual Water Quality Monitoring

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

- Field-measured parameters (dissolved oxygen, temperature, pH, turbidity);
- Total phosphorus and nitrogen compounds (nitrate/nitrite, ammonia nitrogen, total Kjeldahl nitrogen);
- Sulfate;
- Total dissolved solids, suspended solids, and volatile suspended solids;
- Alkalinity, chloride, and fluoride;
- Total organic carbon;
- Phenol;
- Cyanide;
- Indicator bacteria (fecal coliform and E. coli);

[1] For purposes of this analysis, three of the stations were excluded because they are outside of the portion of the CAWS addressed by the Habitat Evaluation and Improvement Study. The excluded stations are AWQM 49 (Calumet River near Lake Michigan), AWQM 55 (mouth of the Lake Calumet connecting channel), and AWQM 86 (Grand Calumet River).

- Chlorophyll;
- Total and soluble metals (arsenic, barium, boron, cadmium, calcium, chromium, iron, lead, magnesium, manganese, mercury, nickel, selenium, silver, and zinc); and
- Volatile organic compounds (benzene, toluene, ethylbenzene, xylenes).

The AWQM water quality parameters were first screened to identify those for which water quality standards did not exist. The remaining parameters were compiled and the results for the period of 2001 through 2007 were compared to their respective water quality standards to identify parameters that might significantly affect fish populations. Fecal coliform was not included in the analysis because it is not typically associated with impacts to aquatic life. Of the other AWQM parameters, the following were measured in excess of their respective water quality standards:

- Boron – The water quality standard for boron was exceeded in 3 of 2,336 water quality samples (0.1%) collected from 2001 through 2007. All three exceedances occurred at one AWQM station.

- Chloride – The water quality standard for chloride was exceeded in 52 of 2,336 water quality samples (2%) collected from 2001 through 2007. These 52 samples exceeded the water quality standard for chloride (500 mg/L) by a relatively small level (136 mg/L on average).

- Fluoride – The water quality standard for fluoride was exceeded in 13 of 2,337 water quality samples (0.6%) collected from 2001 through 2007. These 13 samples exceeded the water quality standard for fluoride (1.4 mg/L) by a relatively small level (0.56 mg/L on average).

- Silver – The water quality standard for silver was exceeded in 56 of 2,336 water quality samples (2.4%) collected from 2001 through 2007. These 56 samples exceeded the water quality standard for silver (0.005 mg/L) by 0.003 mg/L on average.

Due to the extremely low frequency which with these water quality parameters exceeded their respective water quality standards, they were not included in this analysis.

1.3.2 Fish Data

The District has been collecting fish data annually within the CAWS since 1974 (with the exception of 1981 and 1982). During the 2001-2007 period, the District collected fish data at 34 stations within the CAWS on a routine basis. Twenty-six of these 34 stations are part of the District's AWQM program. The total number of sample events across all stations and years includes 113 sample events. These fish data were analyzed to select a set of twelve representative fish metrics for the CAWS. The process for review and selection of fish metrics is documented in a separate report (LimnoTech, 2009). The fish metrics selected for the CAWS Habitat Evaluation and Improvement Study, and used in this analysis, are listed in Table 1-1.

Table 1-1. Fish Metrics used in This Analysis

Metric Abbreviation	Description
%DELT_(n)	% Diseased or with eroded fins, lesions, or tumors
CPUE	catch per unit effort
%LTHPL_(n)	% lithophilic spawners by count
%INSCT_(n)	% insectivores by count
%TC_(wt)	% top carnivores by weight
PRTOL	proportion of Illinois tolerant species
LITOT	IL ratio of non tolerant coarse-mineral-substrate spawners
NMIN	number of IL native minnow species
NSUN	number of IL native sunfish species
GEN	IL ratio of generalist feeders
%INT_(n)	% intolerant species by count
%MOD_(wt)	% moderately intolerant species by weight

1.3.3 Pairing of Fish & Water Quality Data

For purposes of this analysis, it was necessary to pair fish sampling locations with water quality data locations. In the case of the AWQM data, water quality and fish samples are collected from essentially the same location in the system. However, CDOM stations are not necessarily collocated with the AWQM stations. Because of this, the locations of the CDOM stations were evaluated to identify the nearest CDOM station to each AWQM station and then to assess whether the CDOM station was within sufficient proximity to attribute CDOM data to the AWQM.

In some cases, AWQM and CDOM stations are essentially collocated. In other cases, a CDOM station is relatively close to an AWQM, so that the pairing of the two was straightforward. There are, however, instances where the nearest CDOM stations to an AWQM station are miles away or where an AWQM is located approximately equidistant between two CDOM stations. In these cases, the CDOM data upstream and downstream of the SWQM were examined to ascertain whether averaging of the upstream and downstream CDOM would be appropriate. The results of this exercise are presented in Table 1-2.

Table 1-2. Pairing of AWQM and CDOM Stations

AWQM Station No.	AWQM Location Description	CDOM Stn. For DO Comp.	CDOM Stn. For Temp. Comp.
99	Bubbly Creek at Archer Ave.	13	13
58	Cal-Sag Channel at Ashland Ave.	37	37
59	Cal-Sag Channel at Cicero Ave.	39	39
43	Cal-Sag Channel at Route 83	20	20
74	Chicago River at Lake Shore Dr.	21	21
100	Chicago River at Wells St.	10	10
75	Chicago San. and Ship Canal at Cicero Ave.	14	14
40	Chicago San. and Ship Canal at Damen Ave.[2]	-	-
41	Chicago San. and Ship Canal at Harlem Ave.[3]	-	15
92	Chicago San. and Ship Canal at Lockport (16th St)[4]	19	19
42	Chicago San. and Ship Canal at Route 83	16	16
48	Chicago San. and Ship Canal at Stephen St.	17	17
76	Little Calumet River at Halsted St.	35	35
56	Little Calumet River at Indiana Ave.	34	34
73	North Branch Chicago River at Diversey Pkwy.[5]	-	AVG(6,7)
46	North Branch Chicago River at Grand Ave.	9	9
37	North Branch Chicago River at Wilson Ave.	5	6
35	North Shore Channel at Central St.[6]	-	AVG(1,2), 3 in '05
101	North Shore Channel at Foster Ave.	57	57
102	North Shore Channel at Oakton St.	3	3
36	North Shore Channel at Touhy Ave.	-	3
108	South Branch Chicago River at Loomis St.	12	12
39	South Branch Chicago River at Madison St.	11	11

[2] AWQM 40 is located downstream of Bubbly Creek and the nearest CDOM stations are in Bubbly Creek and just upstream of Bubbly Creek; neither of these was deemed representative of conditions at AWQM 40.
[3] AWQM 41 is located between CDOM stations 14 and 15 and the data show poor correlation between dissolved oxygen at CDOM 14 and 15, but good temperature correlation. CDOM 15 is downstream of the Stickney WRP and is likely more representative of conditions at AWQM 41.
[4] AWQM 92 is located between CDOM 18 and 19; there is relatively good dissolved oxygen correlation between these station and good temperature correlation.
[5] AWQM 73 is located between CDOM stations 6 and 7; the data show poor correlation between dissolved oxygen at CDOM 6 and 7, but good temperature correlation.
[6] AWQM 35 is located between CDOM stations 1 and 2; the data show poor correlation between dissolved oxygen at CDOM 1 and 2, but good temperature correlation between CDOM 1, 2, and 3.

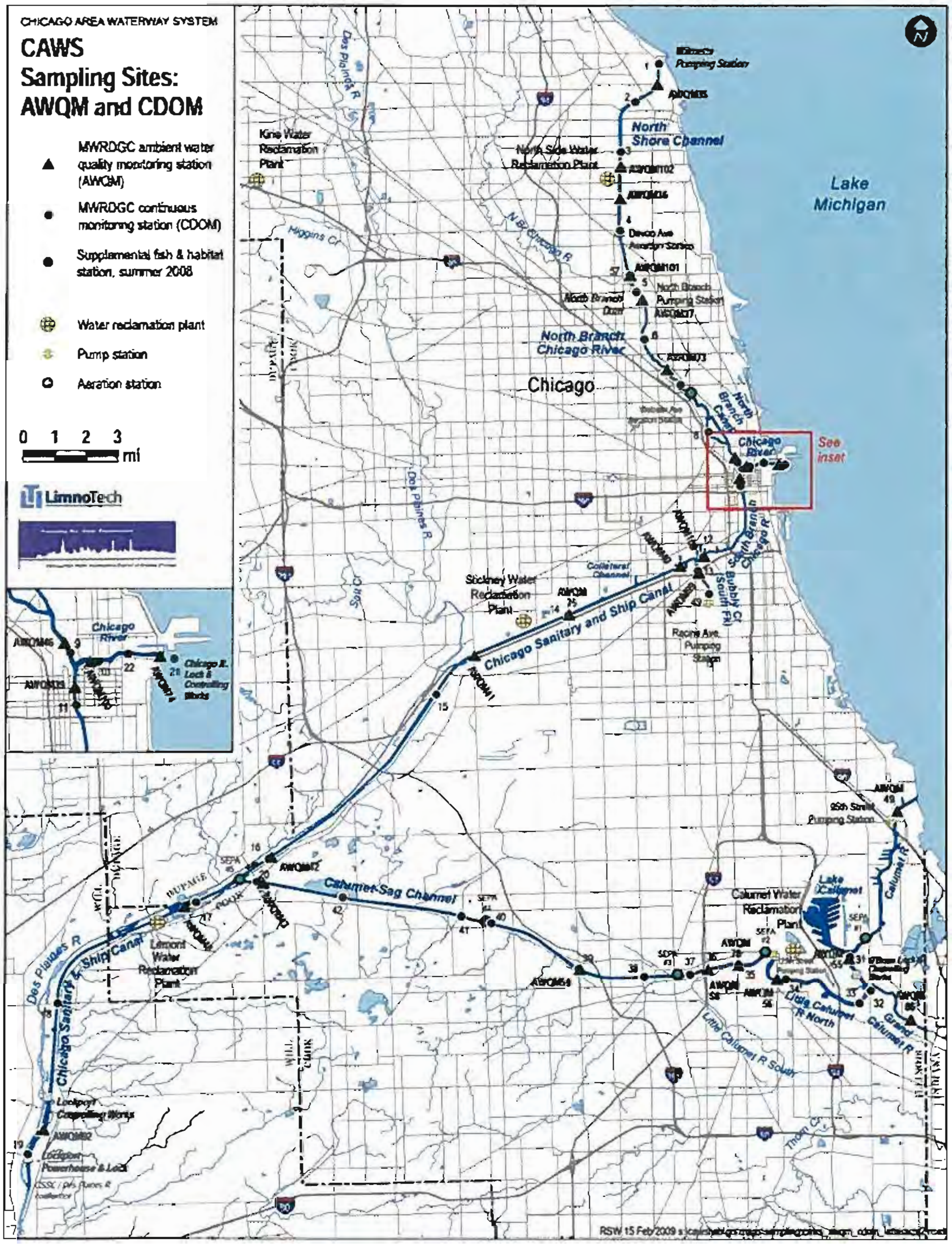

Figure 1-1. CAWS Ambient Water Quality Monitoring (AWQM) and Continuous Dissolved Oxygen Monitoring (CDOM) Locations

1.4 ORGANIZATION OF THIS REPORT

The remainder of this report is organized as follows:

- Section 2 presents the analysis of dissolved oxygen as it correlates to fish data in the CAWS.
- Section 3 discusses the analysis of temperature data as it correlates to fish data in the CAWS.
- Section 4 summarizes the primary findings of this investigation.

Regression plots and summary statistics are included in Attachments to this report.

2. CORRELATION OF FISH DATA WITH DISSOLVED OXYGEN CONDITIONS

As stated in the preceding section, three of the key questions in this analysis pertain to the relationship between fish and dissolved oxygen. The statistical tests conducted to address these questions consisted of:

- Comparison of the sample populations of fish metrics collected during: 1) attainment and 2) nonattainment of water quality standards.
- Regression of fish metrics to the percent of time that the collection station was in attainment with applicable water quality standards.
- Regression of fish metrics to other representations of dissolved oxygen concentrations

The first two sets of tests were conducted both for the current water quality standard as well as the proposed standards. Tests were further stratified to see if significant differences existed between the different use classifications contained in the standards. This section is divided into discussions of:

- Statistical tests conducted
- Results of comparisons of sample populations of fish data representing attainment and nonattainment of dissolved oxygen standards
- Results of correlation of fish data with attainment of current dissolved oxygen standards
- Results of correlation of fish data with other dissolved oxygen indicators

Findings and observations are summarized at the end of this section.

2.1 STATISTICAL TESTS CONDUCTED

A series of statistical tests were conducted to estimate the correlation between observed fish metrics and dissolved oxygen concentrations at different locations in the CAWS. Three specific types of tests were conducted:

- Comparison of the sample populations of fish metrics from observations collected during attainment and nonattainment of water quality standards
- Regression of fish metrics to the percent of time that the collection station was in compliance with applicable water quality standards
- Regression of fish metrics to observed dissolved oxygen concentrations

The first two sets of tests were conducted both for the current water quality standard as well as the proposed standards. Each test is described below.

2.1.1 Comparison of Attainment and Non-Attainment Populations

The first set of tests divided all paired fish-dissolved oxygen measurements into one of two sample populations:

- In compliance with water quality standards, and
- Out of compliance with water quality standards.

"Compliance" with standards was defined as compliance with all representations (e.g. absolute minimum, average) of the standard in the period of time immediately prior to sample collection. If any representation of the standard was not met, the sample was deemed not in compliance.

The non-parametric Kruskal-Wallis test was used to compare the two populations because the sample populations could not be accurately characterized with a standard parametric distribution.

These tests were conducted using different layers of stratification. Specifically, independent investigations were conducted first using the existing water quality standards to define attainment, followed by the same test using the proposed water quality standards. Within each category of water quality standards, additional stratification was considered for each of the use classifications defined in the respective standard. The stratification by use classification could not be fully conducted for all classifications, as insufficient quantity of data existed in some of the classifications to allow rigorous comparisons to be conducted.

2.1.2 Regression to Percent Time in Compliance

The second set of tests consisted of regression of fish metrics to the percent of time that the collection station was in compliance with applicable water quality standards. The entire period of record of dissolved oxygen data was compared to the applicable water quality standard in order to define a percent compliance value for each sampling station.

Standard parametric linear regression tests were conducted for this analysis, as the deviations of errors around the regressions were roughly normally distributed. Exceptions to this are noted as they occur.

Similar to the population comparisons discussed above, these regressions were conducted using different layers of stratification. Specifically, independent investigations were conducted first using the existing water quality standards to define attainment, followed by the same test using the proposed water quality standards. Additional stratification considering the use classifications defined in the respective standard was not conducted, as an insufficient quantity of data existed to allow rigorous comparisons to be conducted.

2.1.3 Regression to Other Representations of Dissolved Oxygen Concentrations

The final set of tests consisted of linear regressions between all observed fish metrics and other representations of dissolved oxygen concentrations (*i.e.*, different than a strict interpretation of the water quality standard). A wide range of representations of the dissolved oxygen concentrations were examined. Results are presented here for the representations that showed the strongest correlations, which consisted of:

- percent of time dissolved oxygen less than 5 mg/l in June through September
- 48 hour average antecedent dissolved oxygen
- 48 hour minimum antecedent dissolved oxygen

Standard parametric linear regression tests were conducted for this analysis, as the deviations of errors around the regressions were roughly normally distributed. Exceptions to this are noted as they occur.

2.2 COMPARISON OF ATTAINMENT AND NON-ATTAINMENT POPULATIONS

This section presents the results of the comparison of fish metrics between two sample populations: 1) data collected during attainment of water quality standards, and 2) data collected during non-attainment of water quality standards. Comparisons are provided both for current and proposed water quality standards. In summary, fish metrics from observations where standards were being attained were generally better than fish metrics where standards were not in attainment, but the differences were not statistically significant. This same finding holds for both the current and proposed standards.

2.2.1 Current Dissolved Oxygen Standards

Analyses for current dissolved oxygen standards were first conducted on a global basis, by considering all data irrespective of designated use classification. Subsequent analyses investigated comparisons specific to each designated use classification (to the extent the quantity of data allowed).

All Designated Uses Combined

Segregation of data into the attainment and nonattainment categories resulted in a total of 36 observations in the attainment category and 15 observations in the nonattainment category. Table 2-1 provides a summary of the statistical characteristics of the sample populations for each of the twelve fish metrics.

Box and whisker plots for each comparison are provided in Attachment A, with an example plot shown in Figure 2-1. The results in Table 2-1 indicate that fish metrics from sites in attainment of water quality standards are generally better than the corresponding metric from sites in non-attainment, with significant differences between the two populations occurring for two metrics. The metrics showing a significant ($p<0.10$) difference are number of native minnows and number of native sunfish.

Table 2-1. Statistical Characteristics of Attainment and Nonattainment Populations (Existing Standards, All Designated Uses Combined)

Metric	Attainment	Nonattainment	Significance*
	Median	Median	
%DELT_(n)	3.6	4.70	0.32
%INSCT_(n)	55.9	71.6	0.55
%INT_(n)	0.0	0.0	0.17
%LTHPL_(n)	75.1	75	0.53
%MOD_(wt)	0.9	1.40	0.82
%TC_(wt)	6.1	6.9	0.51
CPUE	11	7	0.24
GEN	.81	0.87	0.42
LITOT	0.0	0.0	0.49
NMIN	3.0	2.0	0.003
NSUN	4.0	2.0	0.033
PRTOL	0.75	0.80	0.28

*It should be noted that statistical significance is calculated for the data distributions, not the median values.

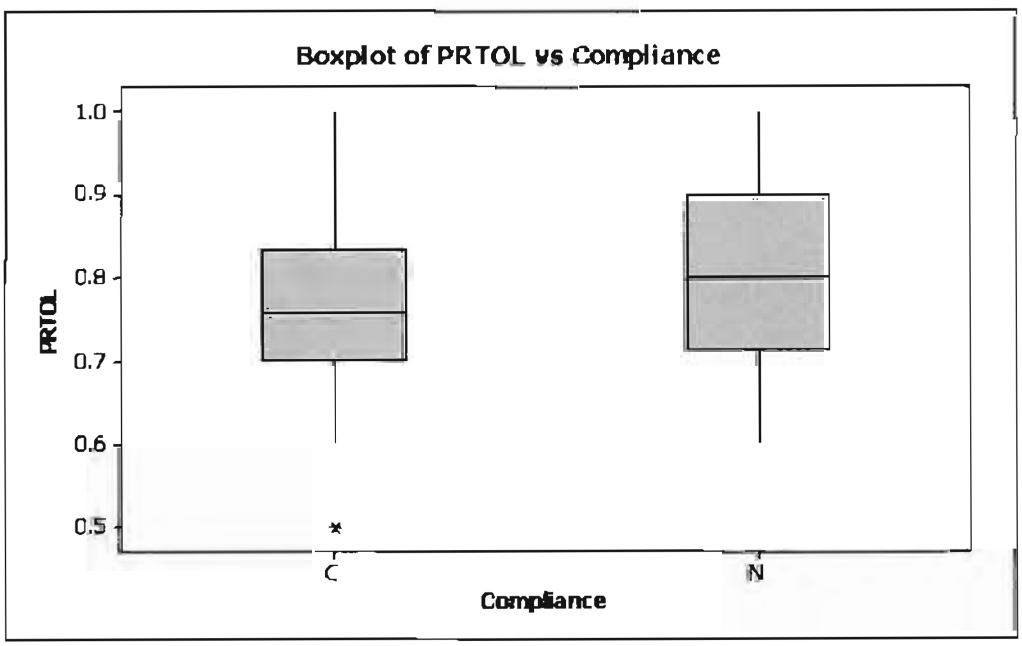

Figure 2-1. Example Box and Whisper Plot Used for Comparison of Populations

(C = data in compliance with D.O. standard; N = data not in compliance with D.O. standard)

Stratification by Designated Use

The Secondary Contact use was the only designated use with sufficient data to conduct a comparison between attainment and nonattainment populations. Segregation of data into the attainment and nonattainment categories resulted in a total of 24 observations in the attainment category and 12 observations in the nonattainment category. Table 2-2 provides a summary of the statistical characteristics of the sample populations for each of the twelve fish metrics. The results in Table 2-2 again indicate that fish metrics from sites in attainment of water quality standards are generally better than the corresponding metric from sites in non-attainment. The stratification of the analysis to focus on the Secondary Contact use increased the number of significant differences between the populations ($p<0.10$) from two to four. In addition to significant differences in number of native sunfish and number of native minnows, additional significant differences were observed for the number of intolerant species by number and the catch per unit effort.

Table 2-2. Statistical Characteristics of Attainment and Nonattainment Populations (Existing Standards, Secondary Contact Uses)

Metric	Attainment	Nonattainment	Significance*
	Median	Median	
%DELT_(n)	3.75	4.3	0.40
%INSCT_(n)	58.9	49.75	0.87
%INT_(n)	0.0	0.0	0.08
%LTHPL_(n)	74.75	77.75	0.92
%MOD_(wt)	1.05	1.45	0.81
%TC_(wt)	6.25	6.5	0.87
CPUE	22.5	8.5	0.09
GEN	0.82	0.87	0.29
LITOT	0.0	0.0	0.35
NMIN	3.0	2.0	0.001
NSUN	4.0	2.5	0.05
PRTOL	0.75	0.79	0.33

*It should be noted that statistical significance is calculated for the data distributions, not the median values.

2.2.2 Proposed Dissolved Oxygen Standards

Analyses for the proposed dissolved oxygen standards were first conducted on a global basis, by considering all data irrespective of designated use classification. Subsequent analyses investigated comparisons specific to each of the two designated use classifications.

All Designated Uses Combined

Segregation of data into the attainment and nonattainment categories resulted in a total of 27 observations in the attainment category and 24 observations in the nonattainment category. Table 2-3 provides a summary of the statistical characteristics of the sample populations for each of the twelve fish metrics.

Box and whisker plots for each comparison are provided in the Attachment A. The results in Table 2-3 indicate that there are no statistically significant ($p<0.10$) differences between fish metrics from sites in attainment of water quality standards and fish metrics from sites not in attainment.

Table 2-3. Statistical Characteristics of Attainment and Nonattainment Populations (Proposed Standards, All Designated Uses Combined)

Metric	Attainment	Nonattainment	Significance*
	Median	Median	
%DELT_(n)	3.1	4.7	0.15
%INSCT_(n)	55.85	71.85	0.10
%INT_(n)	0.0	0.0	0.38
%LTHPL_(n)	77.7	74.7	0.27
%MOD_(wt)	0.85	1.45	0.32
%TC_(wt)	6.0	7.2	0.68
CPUE	8.0	10.5	0.85
GEN	0.82	0.85	0.39
LITOT	0.0	0.0	0.28
NMIN	3.0	2.0	0.46
NSUN	4.0	3.0	0.19
PRTOL	0.76	0.77	0.94

*It should be noted that statistical significance is calculated for the data distributions, not the median values.

Stratification by Designated Use

The available data were split approximately equally across the two designated uses of the proposed standards, allowing the analysis to be stratified into individual analyses for Use Categories A and B.

Segregation of data into the attainment and nonattainment categories resulted in a total of 13 observations in the attainment category and 10 observations in the nonattainment category for Designated Use A. Table 2-4 provides a summary of the statistical characteristics of the sample populations for each of the twelve fish metrics.

Table 2-4. Statistical Characteristics of Attainment and Nonattainment Populations (Proposed Standards, Designated Use A)

Metric	Attainment	Nonattainment	Significance*
	Median	Median	
%DELT_(n)	2.8	4.7	0.17
%INSCT_(n)	53.9	76.1	0.09
%INT_(n)	0.0	0.2	0.66
%LTHPL_(n)	77.7	55.8	0.12
%MOD_(wt)	0.65	1.3	0.21
%TC_(wt)	7.35	12.2	0.14
CPUE	9.5	16.0	0.56
GEN	0.82	0.79	0.75
LITOT	0.0	0.0	0.83
NMIN	3.0	3.0	0.45
NSUN	5.0	4.0	0.61
PRTOL	0.76	0.68	0.22

*It should be noted that statistical significance is calculated for the data distributions, not the median values.

Box and whisker plots for each comparison are provided in the Attachment A. The results in Table 2-4 indicate that fish metrics from sites in attainment of water quality standards are generally better than the corresponding metric from sites in non-attainment, with significant differences ($p<0.10$) between the two populations occurring for only one metric, the number of insectivores by count.

The above analysis was also conducted for Designated Use B. Segregation of data into the attainment and nonattainment categories resulted in a total of 14 observations in the attainment category and 14 observations in the nonattainment category. Table 2-5 provides a summary of the statistical characteristics of the sample populations for each of the twelve fish metrics.

Table 2-5. Statistical Characteristics of Attainment and Nonattainment Populations (Proposed Standards, Designated Use B)

Metric	Attainment	Nonattainment	Significance*
	Median	Median	
%DELT_(n)	4.20	4.7	0.47
%INSCT_(n)	62.0	57.1	0.62
%INT_(n)	0.0	0.0	0.07
%LTHPL_(n)	75.5	75.0	0.69
%MOD_(wt)	1.0	1.9	0.70
%TC_(wt)	6.0	4.90	0.66
CPUE	8.0	7.0	0.59
GEN	0.82	0.87	0.39
LITOT	0.0	0.0	0.07
NMIN	3.0	2.0	0.20
NSUN	3.0	2.0	0.44
PRTOL	0.764	0.778	0.58

*It should be noted that statistical significance is calculated for the data distributions, not the median values.

Box and whisker plots for each comparison are provided in the Attachment A. The results in Table 2-5 indicate that fish metrics from sites in attainment of water quality standards are slightly better than the corresponding metric from sites in non-attainment, but that significant differences between the two populations are uncommon. The only metrics showing a significant ($p<0.10$) difference are % intolerant species by number and the IL ratio of non tolerant coarse-mineral-substrate spawners.

Comparison of Existing and Proposed Standards

Fish metrics from observations where standards were being attained were generally better than fish metrics where standards were not in attainment, but most differences were not statistically significant. This same finding holds for both the current and proposed standards, although the current standards showed a higher number of significant differences than do the proposed standards. This may imply that compliance with current standards is a better predictor of fish health than are the proposed standards.

2.3 REGRESSION TO PERCENT OF TIME IN COMPLIANCE

This section presents the results of regression of fish metrics to the percent of time that the collection station was in compliance with applicable water quality standards. Comparisons are provided both for current and proposed water quality standards.

2.3.1 Current Dissolved Oxygen Standards

Table 2-6 provides regression results between all twelve fish metrics and percent attainment of dissolved oxygen standards for the current standards. Also included is a comparison to a "combined fish metric". This value represents the sum of the standardized values of the non-ACM metrics (i.e., not including %_DELT(n) and CPUE). This "combined fish metric", or CFM, is also used to evaluate physical habitat data in the CAWS. Scatter plots for each regression are provided in the Attachment B, with a sample plot shown in Figure 2-2. The results in Table 2-6 indicate a slight positive correlation between fish metrics and percent attainment of water quality standards. Significant regressions (i.e. slope unequal to zero at a significance level < 0.10) are observed for two metrics, number of native sunfish species and the percent top carnivores. The percent moderately intolerant species by weight metric had a significance of 0.10. R-squared values are less than 0.05 for all regressions except for the three mentioned above, which range from 0.16 to 0.21.

Table 2-6. Regression Characteristics of Fish Metrics vs. Percent Attainment of Dissolved Oxygen Standards, Current Standards

Metric	r^2	Significance
%DELT_(n)	0.03	0.48
%INSCT_(n)	0.0	0.95
%INT_(n)	0.06	0.35
%LTHPL_(n)	0.02	0.62
%MOD_(wt)	0.16	0.10
%TC_(wt)	0.21	0.06
CPUE	0.0	0.87
GEN	0.05	0.40
LITOT	0.05	0.38
NMIN	0.02	0.59
NSUN	0.21	0.05
PRTOL	0.02	0.57
Combined Fish Metric	0.02	0.6

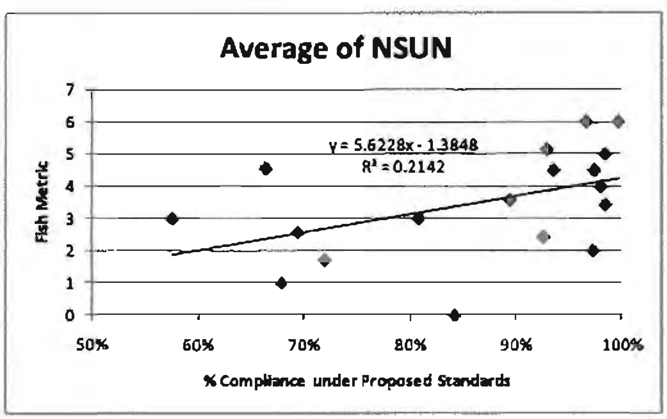

Figure 2-2. Example Scatter Plot Used for Regression of Fish Metrics to Percent Compliance

2.3.2 Proposed Dissolved Oxygen Standards

Table 2-7 provides regression results between all twelve fish metrics and percent attainment of dissolved oxygen standards for the proposed standards. Scatter plots for each regression are provided in the Attachment B. The results in Table 2-7 also indicate a positive correlation between fish metrics and percent attainment of water quality standards. Significant regressions (i.e. slope unequal to zero at a significance level < 0.10) were observed for only one metric, the number of native sunfish. The significance of the regression with the percent top carnivores was 0.10.

Table 2-7. Regression Characteristics of Fish Metrics vs. Percent Attainment of Dissolved Oxygen Standards, Proposed Standards

Metric	r^2	Significance
%DELT_(n)	0.05	0.37
%INSCT_(n)	0.001	0.91
%INT_(n)	0.12	0.17
%LTHPL_(n)	0.02	0.56
%MOD_(wt)	0.15	0.12
%TC_(wt)	0.16	0.10
CPUE	0.02	0.61
GEN	0.03	0.47
LITOT	0.10	0.19
NMIN	0.0	0.89
NSUN	0.30	0.02
PRTOL	0.08	0.26
Combined Fish Metric	0.07	0.28

Comparison of Existing and Proposed Standards

The relationships between fish metrics and attainment of standards are not any stronger for the proposed standards than for the existing standards. In fact, attainment of existing standards appears to have a slightly better correlation to fish metrics than the proposed standards.

2.4 REGRESSION TO OTHER REPRESENTATIONS OF DISSOLVED OXYGEN CONCENTRATIONS

The final set of tests compared all observed fish metrics and other (i.e. different than a strict interpretation of the water quality standard) representations of dissolved oxygen. Results for the representations that showed the strongest correlations to fish metrics are provided below, and consist of:

- percent of time dissolved oxygen less than 5 mg/L in June through September

- 48 hour average antecedent dissolved oxygen
- 48 hour minimum antecedent dissolved oxygen

2.4.1 Percent of Time Dissolved Oxygen Less than 5 mg/l in June through September

Table 2-8 provides regression results between all twelve fish metrics and the percent of time dissolved oxygen concentration are less than 5 mg/l in June through September. Scatter plots for each regression are provided in Attachment B. The results in Table 2-8 also indicate a positive correlation between fish metrics and percent attainment of water quality standards. Significant regressions (i.e. slope unequal to zero at a significance level < 0.10) are seen for over half of the metrics, with four of these significant regressions, including the combined fish metric, having significance levels less than 0.001. Despite the significant regressions, r-squared values are still low, with all but three being less than 0.2.

Table 2-8. Regression Characteristics of Fish Metrics vs. Percent of Time Dissolved Oxygen Less Than 5 in June through September

Fish Metric	r^2	Significance
%DELT_(n)	0.05	0.06
CPUE	0.12	0.004
%LTHPL_(n)	0.005	0.59
%TC_(wt)	0.02	0.24
PRTOL	0.26	8.81E-06
LITOT	0.09	0.01
NMIN	0.16	6.99E-04
NSUN	0.44	9.31E-10
GEN	0.01	0.55
%INT_(n)	0.12	0.005
%MOD_(wt)	0.01	0.35
%INSCT_(n)	6.50E-05	0.95
Combined Fish Metric	0.27	5.91E-06

2.4.2 48-Hour Average Antecedent Dissolved Oxygen

Table 2-9 provides regression results between all twelve fish metrics and the 48 hour average antecedent dissolved oxygen. Scatter plots for each regression are provided in Attachment B. The results in Table 2-9 also indicate a positive correlation between fish metrics and percent attainment of water quality standards. Significant regressions (i.e. slope unequal to zero at a significance level < 0.10) are seen for half of the metrics. Despite the significant regressions, the maximum observed r-squared was 0.17.

Table 2-9. Regression Characteristics of Fish Metrics vs. 48 Hour Average Antecedent Dissolved Oxygen

Fish Metric	r^2	Significance
%DELT_(n)	0.04	0.14
CPUE	0.01	0.38
%LTHPL_(n)	0.002	0.75
%TC_(wt)	0.07	0.03
PRTOL	0.07	0.04
LITOT	0.04	0.10
NMIN	0.08	0.02
NSUN	0.17	6.98E-04
GEN	0.01	0.36
%INT_(n)	0.06	0.06
%MOD_(wt)	0.01	0.41
%INSCT_(n)	0.001	0.77
Combined Fish Metric	0.08	0.02

2.4.3 48-Hour Minimum Antecedent Dissolved Oxygen

Table 2-10 provides regression results between all twelve fish metrics and the 48 hour minimum antecedent dissolved oxygen. Scatter plots for each regression are provided in Attachment B. The results in Table 2-10 also indicate a slight positive correlation between fish metrics and dissolved oxygen. Significant regressions (i.e. slope unequal to zero at a significance level < 0.10) are seen for four of the metrics. Despite the significant regressions, r-squared values are still low, with all but one being less than 0.12.

Table 2-10. Regression Characteristics of Fish Metrics vs. 48 Hour Minimum Antecedent Dissolved Oxygen

Fish Metric	r^2	Significance
%DELT_(n)	0.03	0.15
CPUE	0.002	0.71
%LTHPL_(n)	0.001	0.77
%TC_(wt)	0.06	0.05
PRTOL	0.02	0.30
LITOT	0.04	0.12
NMIN	0.08	0.03
NSUN	0.12	0.01
GEN	0.02	0.32
%INT_(n)	0.05	0.08
%MOD_(wt)	0.03	0.22
%INSCT_(n)	2.78E-04	0.90
Combined Fish Metric	0.05	0.09

2.5 OBSERVATIONS

The statistical analyses presented here support the following observations:

- Fish metrics from observations where standards were being attained were slightly better than fish metrics where standards were not in attainment, but most of the differences were not statistically significant. This same finding holds for both the current and proposed standards.

- There is generally a small positive correlation between observed fish metrics and percent attainment of dissolved oxygen standards. These correlations are also typically not statistically significant. This same finding holds for both the current and proposed standards.

- The relationships between fish metrics and attainment of existing standards are similar to those between fish metrics and attainment of proposed standards, giving no strong indication that the proposed water quality standards will improve fisheries.

- The correlation of top carnivores with water quality standards is worth noting. Top carnivores can be an important indicator metric, because a robust top carnivore population indicates that fish species farther down the food chain are also thriving. In this analysis the percent top carnivores by weight was one of the most strongly correlated variables with the percent of time existing water quality standards are attained ($r^2 = 0.21$; $p = 0.06$). However, although this metric was also correlated with the percent of time proposed water quality standards would be attained, the relationship is noticeably weaker ($r^2 = 0.16$; $p = 0.10$). This indicates that the current water quality standards are sufficient to support top carnivores and that changing the water quality standard for dissolved oxygen will not necessarily improve the percentage of top carnivores.

- There is a statistically significant ($p<0.1$) correlation between dissolved oxygen concentration and several fish metrics. However, the r-squared values for these significant regressions are relatively low (generally less than 0.2, with only three exceptions noted), indicating that dissolved oxygen concentrations alone cannot serve as strong predictor of fish health.

- The dissolved oxygen metric that exhibited the strongest correlations with fish metrics was the percent of time dissolved oxygen was less than 5 mg/L between June and September. Three fish metrics had r-squared values greater than 0.2 for this D.O. metric and one of them (NSUN) had an r-squared of 0.44 ($p<0.000001$), suggesting a significant, relatively strong relationship between that fish metric and that D.O. metric.

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3. CORRELATION OF FISH DATA WITH TEMPERATURE CONDITIONS

As discussed in Section 1 of this report, water quality data from the AWQM and CDOM programs were reviewed to identify water quality parameters, in addition to dissolved oxygen, that should be included in this analysis. For the reasons outlined in section 1.3.1, the only water quality parameter other than dissolved oxygen included was temperature.

For this analysis, temperature data were parameterized to represent two sets of conditions:

- Water quality standards for temperature.
- Temperature conditions in the period immediately preceding collection of fish samples.

Each of these is discussed in detail below.

3.1 REGRESSION TO PERCENT OF TIME IN COMPLIANCE

This section presents the results of regression of fish metrics to the percent of time that the collection station was in compliance with applicable water quality standards relating to water temperature. Comparisons are provided both for current and proposed water quality standards.

3.1.1 Current Temperature Standards

Temperature data collected from CDOM stations in the CAWS were reviewed to identify data events that were not in compliance with water quality standards, as well as the frequency and location of these events. The following observations were made from this review:

- In General Use waters, the only exceedances of temperature water quality standards occurred in 2001 and were limited to two CDOM stations. No exceedances of temperature water quality standards were noted in General Use waters from 2002 through 2007.
- In Secondary Contact and Indigenous Aquatic Life waters, the only events of non-compliance with current water quality standards for temperature occurred in 2001 and 2005. Available data indicated full compliance with water quality standards in 2002, 2003, 2004, 2006, and 2007. Furthermore, the recorded exceedances of the current water quality standard for temperature in these waters were limited to one CDOM location on the Chicago Sanitary and Ship Canal, near the Midwest Generation power plant.

Because only limited exceedances of current water quality standards for temperature occurred from 2001 to 2007, it was decided that evaluation of rate of compliance with the current water quality standards would not be useful in this analysis.

3.1.2 Proposed Temperature Standards

The water quality standards proposed by the IEPA include different use assignments for waters in the CAWS as well as more stringent numeric criteria for temperature. The CDOM temperature data from 2001 through 2007 were evaluated to assess what rates of compliance would have been, had the proposed standards been in place during the data period and how that would relate to fish in the CAWS. The results are presented below.

Percent of Time Daily Maxima Exceeded in Preceding 12 Months

Table 3-1 provides regression results between all twelve fish metrics and the percent of the time the daily maximum temperature exceeded the maximum proposed water quality temperature standard in the twelve-month period preceding each fish sampling event. Scatter plots for each regression are provided in Attachment C and an example is presented in Figure 3-1. Although the results in Table 3-1 indicate a positive correlation between fish metrics and percent attainment of water quality standards, the r-squared values are very low (all less than 0.04). Furthermore, only one of the regressions (NSUN) is statistically significant at the 90% confidence level (*i.e.*, significance < 0.10).

Table 3-1. Regression Characteristics of Fish Metrics vs. Percent of Time Proposed Daily Maximum Temperature Standard Exceeded in Preceding 12 Months

Fish Metric	r^2	Significance
%DELT_(n)	0.003	0.65
CPUE	0.002	0.74
%LTHPL_(n)	0.002	0.71
%TC_(wt)	0.011	0.37
PRTOL	0.004	0.61
LITOT	0.007	0.74
NMIN	0.002	0.74
NSUN	0.038	0.10
GEN	0.028	0.16
%INT_(n)	0.007	0.48
%MOD_(wt)	1.44E-07	1.00
%INSCT_(n)	0.006	0.53
Combined Fish Metric	0.03	0.18

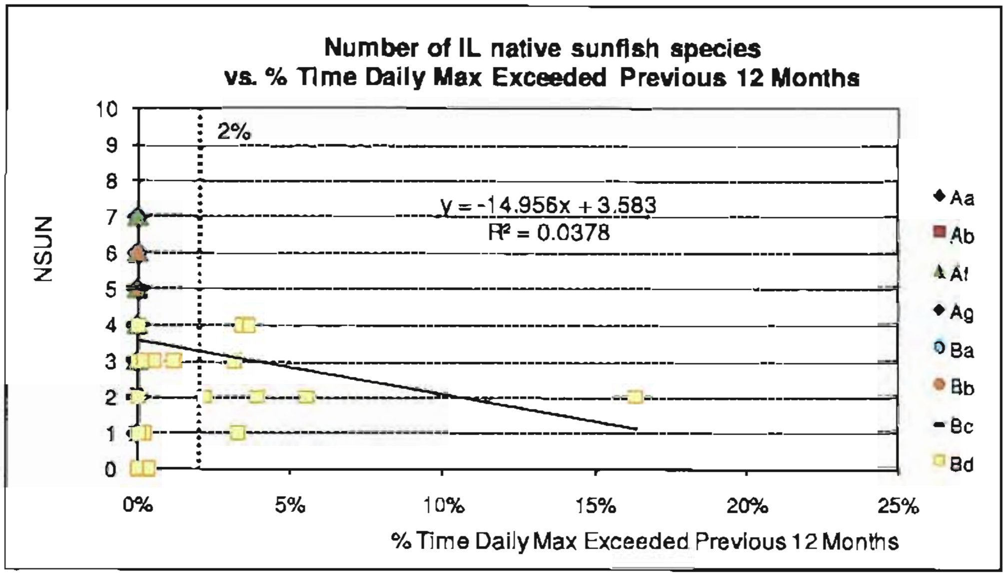

Figure 3-1. Example Scatter Plot Showing Regression of NSUN vs. Percent of Time Proposed Daily Maximum Temperature Standard Exceeded in Preceding 12 Months

Percent of Time Period Maxima Exceeded by More than 2°C

Table 3-2 provides regression results between fish metrics and the percent of the time daily maximum temperature exceeded the maximum proposed water quality temperature standard by greater than 2°C within a regulatory period. Scatter plots for each regression are provided in Attachment C. The results in Table 3-2 indicate a positive correlation between fish metrics and percent attainment of water quality standards, but the r-squared values are all less than 0.02 and none are statistically significant at a significance level < 0.10.

Table 3-2. Regression Characteristics of Fish Metrics vs. Percent of Time Proposed Daily Maximum Temperature Standard Exceeded by greater than 2°C in Regulatory Period

Fish Metric	r^2	Significance
%DELT_(n)	0.009	0.41
CPUE	0.001	0.84
%LTHPL_(n)	0.003	0.64
%TC_(wt)	0.009	0.42
PRTOL	0.008	0.45
LITOT	0.002	0.63
NMIN	0.003	0.63
NSUN	0.014	0.32
GEN	0.019	0.25
%INT_(n)	0.003	0.67
%MOD_(wt)	2.22E-04	0.90
%INSCT_(n)	0.002	0.73
Combined Fish Metric	0.013	0.34

Exceedance of Period Average Temperature

Station compliance with regulatory period average temperature limits was evaluated for correlation with fish metrics, but it was found that only two fish surveys occurred in conjunction with data that would have exceeded the proposed water quality standards for temperature[7]. Because of the very low number of fish sampling events that were concurrent with conditions that would have exceeded the proposed average temperature standard, correlation of that standard with fish metrics was not useful.

3.2 CORRELATION OF FISH DATA WITH ANTECEDENT TEMPERATURE CONDITIONS

Fish metrics were also correlated with temperature conditions antecedent to fish sampling events to identify possible relationships to short-term temperature conditions. The results are discussed below.

3.2.1 24-Hour Antecedent Average Temperature

Table 3-3 provides regression results between all twelve fish metrics and the 24-hour average antecedent temperature (°C). Scatter plots for each regression are provided in Attachment C. As with other comparisons to temperature metrics, the results in Table 3-3 indicate a positive correlation between fish metrics and 24-hour antecedent average temperature, but low r-squared values suggest relatively weak relationships. Only three of

[7] AWQM #75 averaged 32.7°C in August 2005 and AWQM #92 averaged 30.4°C in early September 2002, which were both greater than the average temperature standard for their respective regulatory periods

the individual fish metrics in these regressions were found to have statistical significance at the 90% confidence level (significance level < 0.10): LITOT, NSUN and %INT_(n). The combined fish metric also had a statistically significant r-squared value.

Table 3-3. Regression Characteristics of Fish Metrics vs. 24 Hour Average Antecedent Temperature

Fish Metric	r^2	Significance
%DELT_(n)	0.02	0.21
CPUE	0.02	0.26
%LTHPL_(n)	0.002	0.75
%TC_(wt)	0.02	0.26
PRTOL	0.002	0.74
LITOT	0.04	0.08
NMIN	3.40E-04	0.88
NSUN	0.18	2.13E-04
GEN	0.03	0.13
%INT_(n)	0.05	0.07
%MOD_(wt)	0.02	0.23
%INSCT_(n)	0.01	0.51
Combined Fish Metric	0.06	0.04

3.2.2 48-Hour Antecedent Average Temperature

Table 3-4 provides regression results between all twelve fish metrics and the 48-hour average antecedent temperature (°C). Scatter plots for each regression are provided in Attachment C. These results are similar to those for the 24-hour antecedent temperature condition, with very low r-squared values, and statistically significant regressions only for LITOT, NSUN and %INT_(n).

Table 3-4. Regression Characteristics of Fish Metrics vs. 48 Hour Average Antecedent Temperature

Fish Metric	r^2	Significance
%DELT_(n)	0.02	0.28
CPUE	0.03	0.17
%LTHPL_(n)	0.002	0.73
%TC_(wt)	0.02	0.28
PRTOL	0.003	0.65
LITOT	0.06	0.04
NMIN	4.56E-04	0.86
NSUN	0.21	9.57E-05
GEN	0.03	0.19
%INT_(n)	0.06	0.04
%MOD_(wt)	0.02	0.25
%INSCT_(n)	0.01	0.44
Combined Fish Metric	0.08	0.02

3.3 OBSERVATIONS

The statistical analyses presented here support the following observations:

- As with comparison to dissolved oxygen, there is a slight positive correlation between observed fish metrics and percent attainment of proposed temperature standards, but correlations are rarely statistically significant.

- Very small positive correlations are also apparent between fish metrics and short-term antecedent temperatures, but the correlations are statistically significant only for three individual metrics, LITOT, NSUN and %INT_(n) and for the combined fish metric. The very low r-squared values for these significant regressions indicate that temperature alone is not a strong indicator of fish health.

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4. FINDINGS

The following overall findings can be drawn from this analysis:

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

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

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

These findings indicate that water quality alone is not a sufficient indicator of fisheries in the CAWS and suggest that other factors may also be important to fish in the system. With respect to the primary question stated in Section 1 (*i.e.*, what changes, if any, can be expected solely from an improvement in water quality in the CAWS, if current uses and physical habitat conditions remain unchanged?), while no definitive statement can be made about causation from regression analysis, the weak correlations between fish metrics and dissolved oxygen indicate that incremental improvements in water quality alone may have, at best, a small benefit to fish if all other conditions affecting fish in the system remain unchanged.

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5. REFERENCES

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Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). *Ambient Water Quality Monitoring Quality Assurance Project Plan, Revision 2.1.* November 1, 2007.

Minarik, T.A., J.L. Wasik, M. Sopcak, and S.G. Dennison. *Continuous Dissolved Oxygen Monitoring in the Deep Draft Chicago Waterway System During 2007.* MWRDGC Research and Development Department. August 2008.

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ATTACHMENT A:

BOX PLOTS COMPARING ATTAINMENT AND NON-ATTAINMENT POPULATIONS OF FISH

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