USEPA-Great Lakes Restoration Initiative Project

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Project Title: **Cuyahoga AOC Habitat and Fish Restoration Opportunities**

Final Report

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Abstract

This project evaluated water quality, fish habitat and biota in the Cuyahoga River and Cleveland Harbor, Ohio, in the Lake Erie watershed to set baseline conditions and evaluate existing and potential habitat and fish restoration activities. The lower 5.5 miles (8.9 km) of the river is a dredged ship channel that is maintained to a 23-foot (7m) depth by the US Army Corps of Engineers that leaves this stretch of the river devoid of shallow water fish habitat and has been designated as a USEPA Area of Concern. Yet, it is this stretch of river that out-migrating fish larvae and juveniles must traverse to reach Cleveland harbor and Lake Erie. Our four-year evaluation of abiotic and biotic conditions showed a mix of suitable and impaired conditions. Flow rates, and in particular stream velocity, reached critical minimal conditions in this stretch of the Cuyahoga River; as they were occasionally negative or contrary to the desired flow direction. Ship traffic was observed to exacerbate impaired conditions. Dissolved oxygen (DO) levels did not reach anoxic conditions during the study period in the study area or in a comparison river, the Grand River in Lake County, Ohio. Critical DO levels were only infrequently observed in the lower segments of the Cuyahoga River and Old Channel. Thermal plume issues consisting of temperature spikes near industrial outfalls in the lower river were of concern. Phosphorus levels, measured as Soluble (SRP) and Total (TP), showed that there was bioavailabilty of nutrients to fuel algal blooms in the river, harbor and nearshore Lake Erie; however, both SRP and TP levels were comparable or lower than other similar large Lake Erie tributaries and watersheds. Turbidity and suspended solids were high throughout the study period at all river and harbor stations. This had a significant dampening effect on light transmission in the water column and energy available for aquatic vegetation and green algae growth. Other water quality parameters monitored during the study period revealed conditions that were suitable for warmwater aquatic life and were similar to the reference river (Grand River, Ohio). Zooplankton, benthos, and edible green algae levels were recorded in the study area, but appeared somewhat impaired compared to reference and Lake Erie sites; food quality for fishes was diminished in the lower Cuyahoga ship channel. Lower trophic levels and the food web were impacted by aquatic invasive species. Larval fish were produced and transported through the lower section of the Cuyahoga River and in the harbor during each year of the study; most production was Emerald Shiners and Gizzard Shad, but 12 other fish species and fish eggs were observed in our ichthyoplankton samples. In areas where shallow water and habitat complexity were present, a more diverse complex of resident fish species and juvenile transient (Lake Erie) fish species were observed in comparison to areas that had greater depths and sheet-pile lined river banks. Indices of Biotic Integrity were in the fair range and were comparable to nearshore and offshore Lake Erie sites in the central basin. Observed fish anomalies (DELTs) in the lower Cuyahoga River were at, or lower than, benchmarks set for impairment. Public boater (launches) and angler access in the middle and lower portions of the river were inadequate for current and anticipated demand as this AOC completes remediation. Future actions to remediate the lower section of the Cuyahoga River and Cleveland Harbor should address thermal issues, ship channel flow regime, turbidity and suspended solids, watershed contributions to the ship channel “reservoir”, access, ameliorating nearshore and riverbank hardening, and improving shallow water habitat complexity. Without these water quality and habitat improvements, impairments will persist, and restoration activities may not achieve their intended outcomes. Changing OEPA impairment thresholds make delisting attainable for many of the BUIs. Regional controlling factors may play a large part in fish production and activity in the lower watershed, as transient species like Walleye, Yellow Perch, White Bass and White Perch were sampled 10 miles upstream in the Cuyahoga River in late summer 2015.

Introduction

The Cuyahoga River is a 122-mile long river that meanders in a “U” shape from Northeast Ohio’s rural, but developing, Geauga County south through Kent, then it turns west into the city of Akron. There it leaves the confines of Akron and turns north through the Cuyahoga Valley National Park, before making its way through the heart of downtown Cleveland and emptying in Lake Erie. This diverse watershed of 810 square miles contains a wide variety of habitats, land uses and human population densities from rural forests and fields to industrial urban metroplex landscapes of two Midwestern cities. The Cuyahoga River is best known as “the river that burned” because of pollutants, industrial impacts and neglect over many decades in the 1900s. It became a symbol of impaired resources that helped lead to the development of the national Clean Water Act of 1972. Its waters have been dammed, extracted, used and recycled back into the river channel and Lake Erie. Impairments to water quality in the Cuyahoga River come from non-point and point sources; from agriculture and suburban runoff, from wastewater treatment plants, combined sewer overflows, industrial discharges, and from miles of hardened river edge and shoreline with concrete and steel sheetpile placement and bulkheads. Much of what remains as current impacts comes from impairments and wastes generated or processes established decades ago, and remediation has been slow, difficult and costly.

In 1985, the International Joint Commission’s Water Quality Board designated the Cuyahoga as one of 43 Areas of Concern (AOC) that had beneficial use impairments (BUIs) and degraded aquatic life conditions. Remedial Action Plan (RAP) teams, an outgrowth of the AOC designations, began work to restore beneficial uses in AOC watersheds. The Ohio Department of Natural Resources, Division of Wildlife (ODNR-ODW) is one member of a team of agencies and stakeholders that participate in the Cuyahoga River RAP which was founded in 1988 for support of local RAP activities. The Great Lakes Water Quality Agreement (GLWQA) lays out 14 beneficial use impairments (BUIs) that must be remediated in order to restore the AOCs. In many ways these BUIs reflect the same goals as represented in the Ohio water quality standards for attainment of beneficial uses. The BUIs include:

1. restrictions on fish and wildlife consumption*;
2. tainting of fish and wildlife flavor;
3. degradation of fish and wildlife populations*;
4. fish tumors or other deformities*;
5. bird or animal deformities or reproductive problems;
6. degradation of benthos*;
7. restrictions on dredging*;
8. eutrophication or undesirable algae*;
9. restrictions on drinking water or taste and odor problems;
10. beach closings*;
11. degradation of aesthetics*;
12. added costs to agriculture and industry(*);
13. degradation of phytoplankton and zooplankton populations; and
14. loss of fish and wildlife habitat*.

The 1992 Stage I report identified 10 of 14 beneficial uses as not meeting attainment in the early years of Cuyahoga River AOC designation (designated above with an asterisk-*). Within the last decades, however, with focus on activities that could improve the health of the watershed, some of these beneficial uses have been obtained (Cuyahoga RAP and OEPA 2009 report). Other beneficial use impairments (BUIs) such as degradations in fish populations, benthos and fish habitat are beginning to improve and may be approaching delisting targets; this study, in part, evaluates progress towards that goal of delisting the Cuyahoga River AOC designation.

In 1998, then-President Clinton recognized the Cuyahoga River as a national American Heritage River because of its historical and environmental importance. The Cuyahoga RAP team continues to work on projects that improve the watershed with the goal of delisting and improving ecosystem health including: dam removal or remediation (Monroe Falls, Kent, Cuyahoga Falls), storm water control and management, CSO and water treatment plans, establishment of sub-watershed focus groups, and habitat improvement projects (corridor protection, land use management, "green" bulkheads, natural buffers, instream and streambank habitat restoration). This project complements these efforts and recommends areas for focusing future restoration and protection work. It establishes baseline information and adds this information to databases for future evaluations and comparisons. Many of the projects being implemented or proposed have no baseline abiotic and biotic data to draw from to gauge the success of their improvement projects.

One constant in this watershed for the last century has been the use of the Cuyahoga River for industry. The lower Cuyahoga River supports Cleveland Harbor and the movement of steel and iron products, stone, sand, salt, and other raw and finished products. Large commercial-draft ships use this harbor and the lower Cuyahoga River to offload or take on these products. Because of that usage, and because of the silt load being carried down the river from the upper watershed, the lower river and harbor are dredged by contractors overseen by the U.S. Army Corps of Engineers to depths ranging from 23-30 feet (7-9m). This river and harbor dredging affects the natural hydraulics and ecosystem function of the water area, with surveys showing that many parts of this area experience low dissolved oxygen levels as early as May (OEPA 2009, CRCPO 2002, NEORSD 2003), which can affect survival of fish and other aquatic biota. Dredging also affects loss of vital aquatic habitat in the immediate area and increases turbidity, which may lead further degradation of water quality during time periods when fish and aquatic invertebrates are reproducing or migrating back to the lake or harbor.

The ODNR, Division of Wildlife currently reviews dredge programs in the ship channel and harbor and make recommendations to minimize impacts during seasonal spawning windows. Fish species that spend much of the year in Lake Erie or adjacent nearshore harbors ascend into the river seasonally during the spring to spawn. Larval and juvenile fish produced in the river then out-migrate through the summer. Randy Eschenroder of the Great Lakes Fishery Commission (GLFC) hypothesized that large rivers like the Cuyahoga could be suitable for migratory runs of spawning Walleye (*Sander vitreus*), similar to other rivers in Lake Erie such as the Maumee, Sandusky, Grand (Ohio), Grand (Ontario), Buffalo, and Cattaraugus Creek. Certainly historic records show that native fish species like White Bass (*Morone chrysops*), Smallmouth Bass (*Micropterus dolomieu*) and Largemouth Bass (*Micropterus salmoides*), other sunfish and crappies (centrarchids), Freshwater Drum (*Aplodinotus grunniens*), Lake Whitefish (*Coregonus clupeaformis*) and Cisco (*Coregonus artedi*), Northern Pike (*Esox lucius*) and Muskellunge (*Esox masquinongy*), Walleye, Sauger (*Sander canadense*) and Blue Pike (*Sander vitreus glaucus*), suckers and redhorses (catostomids), forage and prey fish (cyprinids), and even possibly Lake Sturgeon (*Acipenser fulvescens*) used rivers and nearshore areas like those originally documented in the Cuyahoga River and harbor for spawning.

Within the scope of the GLRI RFP for 2010, Focus Area I.D. 2: “Habitat and Wildlife Protection and Restoration: Habitat Restoration in Great Lakes Areas of Concern” was applicable for this project. The activities in this project address work toward delisting of the Cuyahoga River and harbor AOC. They establish a comprehensive description of conditions and critical areas in the ship channel and harbor and assess conditions in the lower river (AOC) downstream of Akron. Results and management implications of this project will inform other projects and activities in the watershed and aid in siting and concentrating future work toward achieving AOC delisting, restoring habitat, and improving ecological function.

This project addresses points identified in the Great Lakes Restoration Initiative (GLRI) for providing healthy ecosystems for fish and wildlife. Within the 2010 GLRI funding plan, problem statements in Focus Areas 1 (Toxic Substances and Areas of Concern), 3 (Nearshore Health and Nonpoint Source Pollution) and 4 (Habitat and Wildlife Protection and Restoration) identify habitat and ecosystem problems, describe long term goals, and discuss principal actions to support funding this project. Habitat and wildlife protection and restoration was a key concept, with projects that address habitat destruction and degradation, knowledge gaps and strategic and measurable environmental outcomes proponents to be addressed. AOCs, such as the Cuyahoga, were identified as a priority, and this project provided opportunities for interagency and multiple organizations’ collaboration to move together as we seek delisting of the AOC and restoration of ecosystem function in the Cuyahoga River and harbor. This goal of healthy communities and ecosystems and the strategic targets of delisting AOCs and managing sediments are also reiterated in the USEPA’s Strategic Plan, sub-objective 4.3.3. Regional collaboration on activities through the RAP is presented via the web at: *http://www.cuyahogariver.org/* and *http://www.epa.gov/glnpo/aoc/cuyahoga.html* .

The findings of this project have other applications and relevance as well. Within the confines of the Great Lakes Regional Collaboration (GLRC) Strategy, and the Ohio portion of that Strategy, there has been defined a need for more habitat conservation and species management and an acceleration of cleanup activities in AOCs. They also identified the need for a technologically sound information base, baseline data, and representative indicators- which gets to the core of this project. They also pointed toward collaborative sustainability, including improved planning and resource and economic management. The GLRC Strategy Team issued recommendations on the habitat and species issues that focused on safe and healthy habitats for native fish species and healthy fish communities, and protected, restored, and managed coastal, connecting and open water areas. Focus areas for study that coincide with this project include inventory and assessment of Great Lakes coastal habitats for restoration and protection, and detailed monitoring of AOCs in riverine and coastal shore areas.

Results of this project will lead to improved quality of the ecosystem and definition of blueprint-area goals: the synthesis of project results identify key aquatic species and communities, as well as define the status of ecological conditions and impairments, conditions or success of any external restoration work, and define abiotic processes that may regulate future aquatic ecosystem health. This project addresses concerns of the three leading impairments in the Cuyahoga AOC: degraded fish and wildlife populations, degraded benthos, and loss of fish and wildlife habitat. The results of this project describe impairments of chemical, physical and biological degradation from human activities such as changing hydrology, pollution, storm water and dredging effects, as well as evaluating activities to ameliorate these effects by other restoration projects in the watershed. This project also completes assessment of current conditions toward evaluations of impairments in fish tumors, plankton populations, and eutrophication, nuisance algae and harmful algal blooms.

Data, photographic records and products produced during this project will be applicable and compatible to other key work in the Lake Erie watershed and meet or exceed standards for data and products in use by USEPA-GLNPO, ODNR-ODW, OEPA, the Great Lakes Fishery Commission's Lake Erie Committee task groups, the Northeast Ohio Regional Sewer District, and the Cuyahoga Remedial Action Plan working group and its partners. Data was collected via common sampling methods used by the US Army Corps of Engineers, USEPA, Ohio Division of Wildlife, Ohio EPA, and the Northeast Ohio Regional Sewer District for hydroacoustics, fisheries, lower trophic level sampling and water quality monitoring to insure quality control, comparability, and interagency usability of data or results.

Outcomes of this project include:

- the description of seasonal changes in the natural aquatic communities, ecosystems and abiotic processes in the Cuyahoga River and harbor to be applied by researchers for completion of the blueprints for biodiversity protection and restoration in the Lake Erie basin
- identification of native fish stocks that reproduce and whose health depends on or can be enhanced by the restoration of Cuyahoga River and harbor
- identification of critical aquatic habitats and key sportfish stocks, and restoration of habitats to support rehabilitation of native fish species in the Cuyahoga River and harbor
- assisting in the improvement of beneficial use impairments / abiotic and biotic conditions that will lead to the delisting of the Cuyahoga River and Harbor as an Area of Concern
- project findings, products, maps and data that inform Great Lakes, Ohio and Cuyahoga watershed decision makers and managers to determine future watershed quality and aquatic life targets, implement additional protection and restoration actions, and adjust actions that significantly impair watershed function.

Outputs of this project include:

- identification and mapping of key critical areas for habitat protection and areas ideal for habitat restoration and rehabilitation in the Cuyahoga River and Cleveland harbor
- habitat and aquatic life information that will aid external researchers in the development of the biodiversity blueprints and restoration plans for Lake Erie
- identification and enumeration of key fish species' densities and aquatic species using and spawning in the Cuyahoga River, harbor, and breakwall areas
- data results and products that become a part of a larger framework of databases associated with Great Lakes coastal, harbor, sub-watershed and riverine areas and Cuyahoga AOC resources.

Results of this project include:

- Mapping approximately 10 square miles of harbor, nearshore and breakwall areas, and side channels (Cuyahoga's old river channel area) for habitat delineation; prioritized for protection, rehabilitation and restoration in the Cuyahoga River and harbor AOC. Completion of additional habitat evaluations for comparison purposes, in the Cuyahoga River up to the dam at Ohio State Route 82 and in the neighboring Grand River.

- Databases of abiotic conditions and biotic life during the project time period to substantiate current baseline conditions and to describe changes during the project time span. Comparisons to index metrics that compare gathered project data to AOC and other evaluation standards.
- Data, results and conclusions to inform activities of in-stream and harbor work; dredge and fill operations; riverbank armoring maintenance, repair and remediation; management implications for Lake Erie and Cuyahoga River fish species; and completion of restoration activities to benefit restoration of native aquatic species in the Cuyahoga River and harbor AOC.

Study Area

This Cuyahoga AOC Habitat GLRI project area consists of the following major regions along Ohio's portion of the Lake Erie watershed (Figure 1): (1) the lower Cuyahoga River – from the first riffle below the Harvard-Denison Rd. bridge through the ship channel to the river mouth in Cleveland Harbor; (2) the Old (River) Channel from Channel Park Marina down to its confluence with the Cuyahoga River just above the river's mouth; (3) Cleveland Harbor from Edgewater Park on the western edge to Dike 14 on the eastern edge; (4) nearshore Lake Erie waters adjacent to the Cleveland Harbor east-west breakwall; (5) the middle section of the Cuyahoga River from the dam just upstream of the State Route 82 bridge in Brecksville downstream to the Harvard-Denison bridge; (6) comparison sites on the Grand River in Lake County, Ohio, from the first riffle in Painesville Twp. (located downstream of the State Route 2 bridge) downstream to the mouth in Fairport Harbor.

With the exception of several water samples taken for elemental chemical signature analyses, all field work in 2012 through early 2015 was in the first four regions and region six described above; the majority of work during the 2011 field seasons occurred in the first five regions of the project study area. Standardized sample locations for field work and data reporting were determined prior to and during the first field year, and they are delineated in Figures 2 and 3. Sample location abbreviations will be used throughout this document and in subsequent Appendices. Sample locations are described and georeferenced in Table 1.

In 2013, the GLRI project was coordinated with a project run by the Cuyahoga County Planning Commission (CCPC) that evaluated habitat improvements on the Cuyahoga River under the term of "Green Bulkheads." The Green Bulkhead project is funded separately and completely through the U.S. Army Corps of Engineers, to assess ways to improve habitat and water quality using "green" and biomimicry methodologies instead of vertical steel sheetpile. Many of their sampling and assessment activities are similar in scope and timing, and our data was used to inform their project and process. The Green Bulkhead project is scheduled to continue through 2016, beyond the GLRI project, to fully evaluate specific CCPC project habitat installations. They have dovetailed many of the sample locations and sample activities from our project for the Green Bulkhead project instead of working at cross-currents and duplications of effort. Sample sites included those on the Cuyahoga River, as well as at control sites on another river, the Grand River in Lake County, Ohio, for comparison and reference. We have included a list and map of project locations on the Cuyahoga River, Old (Cuyahoga River) Channel, Cleveland Harbor, Outer Breakwall and Grand River (Table 1, Figure 4) and will refer to comparisons of sample results from the Grand River sites to highlight important significant differences or similarities between these two river systems.

Table 1. Descriptions of project study area sampling and monitoring locations.

Sample Stations		Latitude	Longitude
Location / Code	Site name/description	N	W
Cuyahoga River			
LR0	first riffle above nav channel	41° 27.230'	81° 41.023'
LR1	head of nav channel	41° 27.903'	81° 40.464'
LR1h	old habitat project area	41° 28.341'	81° 40.164'
LR2 (also LR2s)	Scranton Rd/Scaravelli Marina	41° 29.296'	81° 41.611'
LR2itb	Irish Town Bend	41° 29.359'	81° 42.232'
MR1	St Rt 82 dam	41° 19.260'	81° 35.246'
MR2	Rockside Rd. bridge	41° 23.602'	81° 37.673'
TC1	Tinker's Creek (mouth)	41° 27.917'	81° 36.501'
Old (River) Channel			
OC1	upper Old Channel	41° 29.510'	81° 43.217'
OC2	lower Old Channel	41° 29.852'	81° 42.680'
Cleveland Harbor			
H1	west Harbor	41° 30.100'	81° 43.115'
H2	east Harbor	41° 31.988'	81° 39.561'
Cleveland outer breakwall			
OB1	west nearshore	41° 30.404'	81° 43.502'
OB2	east nearshore	41° 32.387'	81° 39.901'
Grand River			
GR1	at St. Clair Street bridge	41° 44.495'	81° 15.755'
GR2	nav channel @ salt dock	41° 45.153'	81° 16.813'
Data Sonde Locations			
Cuyahoga River			
LR0	RR bridge below 1st riffle	41° 27.253'	81° 41.042'
LR1	I-490 bridge	41° 28.702'	81° 40.385'
LR2	I-90 bridge	41° 29.210'	81° 41.477'
LR3	Samsel's	41° 29.878'	81° 42.190'
Grand River			
GR2	Grand River Sailing Center	41° 44.829'	81° 16.860'

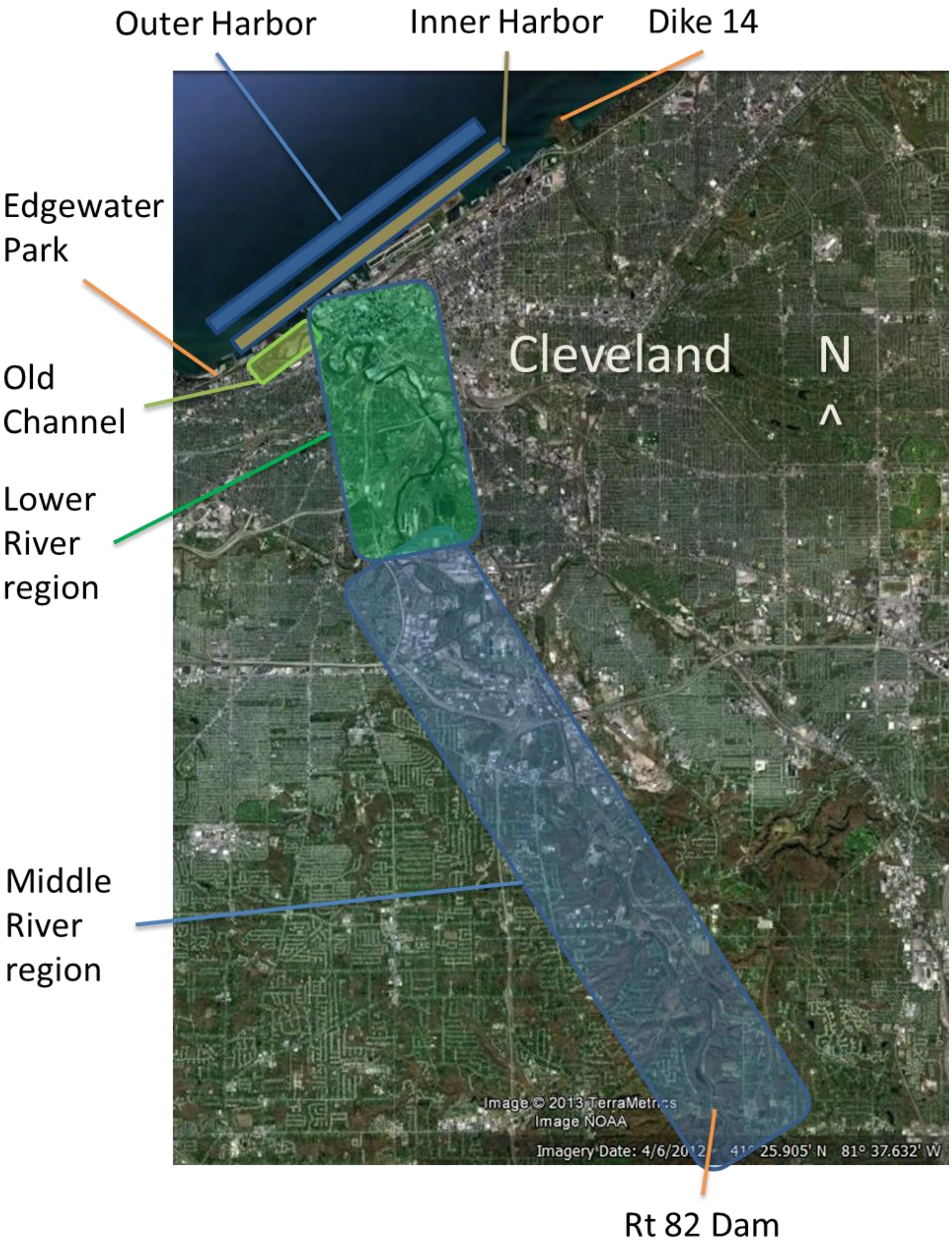


Figure 1. Cuyahoga AOC Habitat GLRI project study area delineated by region. Map generated by Google Earth Maps.

Figure 2. Standardized sample locations and their abbreviations for the Cuyahoga AOC Habitat GLRI project in the lower river, harbor and adjacent open waters. Map generated by Google Earth Maps.

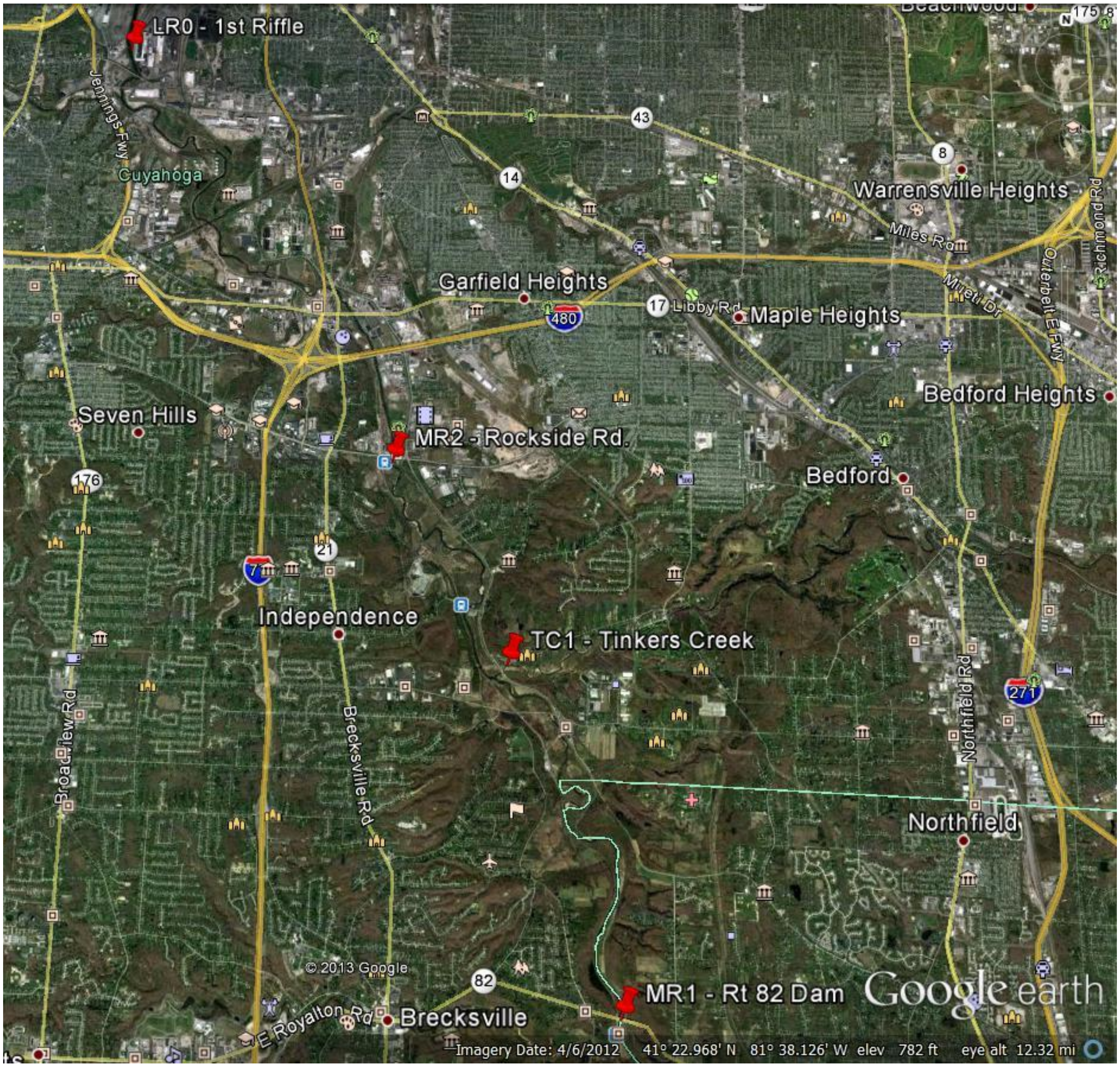


Figure 3. Standardized sample locations and their abbreviations for the Cuyahoga AOC Habitat GLRI project in the middle river region. Map generated by Google Earth Maps.

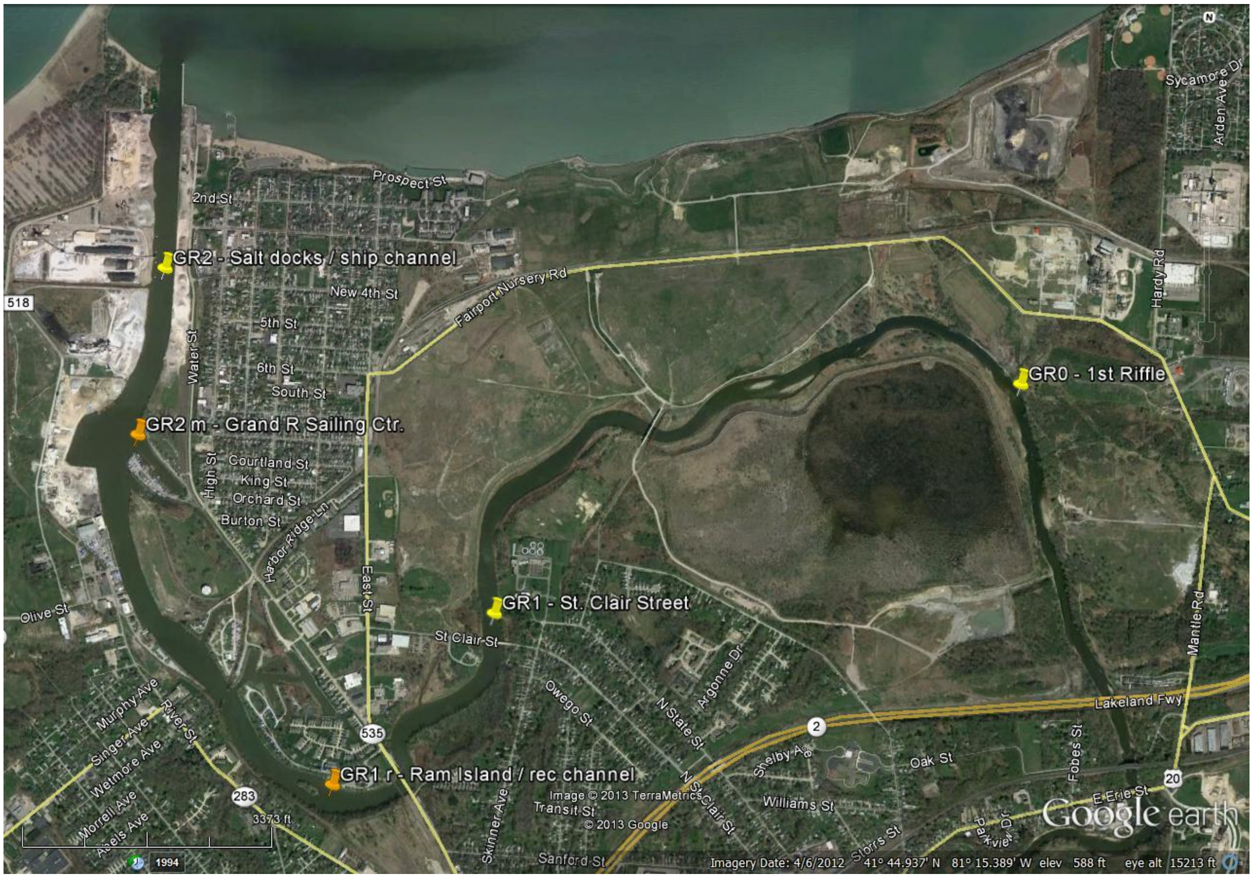


Figure 4. Standardized sample locations and their abbreviations for the CCPC Green Bulkhead project control sites in the lower Grand River. Map generated by Google Earth Maps.

Methods

In this section we describe the sampling procedures employed throughout the project to assess current conditions in the project study area. For electronically-recorded, internet-posted external field data obtained for lake levels, river flow and stage, and continuous water quality data, we gathered that information on regular intervals (quarterly) or when needed (daily) prior to a specific sampling activity or field date, in order to capture and download available ranges of continuous data recordings as they are posted on their respective websites. These verified external data were saved on ODW computers with redundant backups for use with other sample data and to describe or calculate statistical results of conditions observed during the study period in the project area. When data loss was observed, we used “nearest neighbor” - applicable data in either time or location to characterize potential changes during the time period when data was missing. All data recorded and maps generated for this project are saved electronically and will be made available as a part of the final report package. Contact the PI for specific public data requests.

For water chemistry samples, we employed an ODW small boat or research vessel to arrive at each station’s location using GPS. At each station, we completed water temperature, dissolved oxygen, and light penetration profiles in the water column from the surface to just above the bottom sediment. Meter values were generally hand-recorded on data sheets in pencil or indelible ink, unless the meter actively recorded data results electronically. Station location number, date, time and types of samples completed were recorded on a Water Chemistry Sample data sheet. Secchi disk transparency was taken at each station to the nearest 0.1m as well as collecting water samples by overboard sampling and storing in cups or jars for external (contract) analyses for chlorophyll *a* , total and soluble reactive phosphorous, and trace element microchemistry. Replicate samples for offsite analysis were labeled by location, date, and sample number, removed to boxes and/or coolers for storage and delivery to our ODW lab and then delivery to external labs. Electronic data, including inventory of external samples, was downloaded from meters daily (with the exception of installed YSI data sondes which were downloaded approximately every 4-6 weeks). Handwritten data was entered into our computer databases, and all data was warehoused in redundant ODW computer databases.

During the study period, we recorded continuous flow rate data from gaging stations in the Cuyahoga River and Grand River at gage stations that were not located in the navigational ship channels. We required active measures of the flow rate velocities observed at specific locations in the ship channels as they were significantly different than areas that had riffle-pool-glide development. These ship channels represent an important component of the migratory travel route of larval and juvenile fishes. So in 2014 and early 2015, we measured stream velocity to the nearest 0.1 at each river station with the other abiotic field data using a Xylem Flow Pro FP211 meter.

Partway into this project, and in concert with other Cuyahoga River habitat projects, we installed YSI EXO data sondes at three stations in the Cuyahoga River and one station in the Grand River to obtain continuous data on selected water quality parameters of interest from June through October, 2014. Data collected included: water temperature (nearest 0.1 degrees C), dissolved oxygen (mg/l), dissolved oxygen %saturation, pH, conductivity, specific conductance, turbidity, total dissolved solids, blue green algae concentration (ug/l), chlorophyll a (ug/l) concentration, and salinity (per 1000s). These data were downloaded from the YSI EXO sondes on a regular basis in 2014 and early 2015 and compared to field station results and other continuous data sources (Heidelberg University National Water Quality lab reports).

Phytoplankton and zooplankton were sampled at the water chemistry sites by deploying a 64-micron mesh tapered plankton net with an aluminum hoop opening diameter of 0.5 meters and a glass mason jar on the end. A General Oceanics Environmental flow meter was attached across the diameter of the net opening, and meter readings will be taken before deployment and after retrieval, in order to calculate the volume of water sampled in the vertical tow of the net. Plankton samples were retrieved via a vertical tow of the net after it was lowered to the lake or river bottom just to the point where the weight comes in contact with the sediment. After raising the net, the contents were washed down by splashing surface water on the outside of the net and decanting the plankton down into the sample jar via a squirt bottle applying water to the lower exterior portion of the net. Samples were fixed in 90% ethanol for delivery with chlorophyll *a* samples to our OSU contractors for workup, with results and analysis returned to the PI.

Samples of benthic fauna were taken at the above water chemistry sample sites in the lower river and harbor. Benthic invertebrates were sampled by lowering a Ponar or Ekman dredge to the bottom and deploying the grab mechanism. Sediment samples were washed down and sifted through U.S. standard sieves of #30 mesh (coarse, 0.0232-inch opening) and #40 mesh (medium-fine, 0.0165-inch opening). Subsamples were returned to the lab for analyses and for comparison to NEORSD Hester-Dendy samplers that were deployed in the Study Area. All benthic samples were frozen and then transferred to glass sample jars containing 90% ethyl-alcohol solution for preservation and further counting in the lab. Lab processing enumerated individuals of functional taxa (family) per sample for data entry, database compilation, and calculation of standard Qualitative Macroinvertebrate Index (QMI) and Invertebrate Community Index (ICI) metrics.

Lower Trophic Level (LTL) sample field datasheets and their accompanying databases record date, station number, frequency of appropriate samples, and geospatial data. Lab data sheets recorded numbers and types of individuals sampled at each station, by date and sample replicate, or catch record number (CRN). Some sampling methods like benthic or aquatic vegetation analyses, or QHEI and QMI, were completed and recorded by hand on “catch” data sheets or field data sheets, while other sampling techniques like plankton analyses and counts, IBI, ICI and MIwb indices’ calculations were generated from metadata and samples stored and brought back to the lab. Samples for offsite analysis were labeled by location, date, and sample number (CRN), removed to boxes and/or coolers for storage and delivery to storage and lab facilities at our ODW-Fairport lab. Catch data sheets were hand recorded in the field or lab, and all corresponding data was entered and archived in the ODW-Fairport and ODNR computer systems for subsequent analysis and reporting. Examples of all forms are included in the Appendix.

For aquatic vegetation assessments, we proposed a series of transect surveys in late summer in order to describe the presence of species of floating, rooted and emergent aquatic vegetation by species. These proposed sampling procedures involved hook or rake sampling from a compass rose of eight directions at each specified station, then processing individual pulls or aggregating samples at a station, and counting stalks and weighing biomass of aquatic vegetation *en masse* and by species. Our field surveys over multiple years encountered only little pockets of dense vegetation in the harbor, marinas, and side channels of the lower river. Mapping and qualitative discussion of our findings were completed and are presented for this report.

Fish samples were obtained primarily via boat electrofishing, ichthyoplankton trawls, and hydroacoustics. Fish sample collection procedures paralleled those completed by ODW, OEPA and NEORSD fisheries surveys and evaluations. We employed ODW boats in the project study area to perform stream pulsed-DC electrofishing along defined transects. Conductivity meter readings were used to set up adjustments to electrofishing unit operation. ODW catch data sheets were used to record date, catch record number (the sample number in sequential order), survey methods used, duration of fishing effort, location, and numbers of fish caught by species, weight (kg), and age code. For electrofishing methodology metadata, we recorded voltage, amps, pulse frequency, pulse width, and seconds (elapsed time) and distance (km) electrofished. Catch data sheets were hand recorded in the field or lab. All corresponding data was entered and archived in the ODW-Fairport computers, backup external hard drives, and in ODNR computer systems for subsequent analysis and reporting. Examples of all ODW forms are included in the companion dataset with this project.

Qualitative evaluations of habitat (QHEI and QHEI-L), macroinvertebrates (QMI) and modified Invertebrate Community Index (ICI) calculations were obtained from samples in the lower river section of the Cuyahoga River and Cleveland Harbor.

Hydroacoustic samples for bottom bathymetry, habitat typing, or fish density sampling was obtained using ODW-Fairport boats, operating along defined transects or grids while employing a pinging transducer of known frequency and range, georeferenced spatial GPS data, and an onboard laptop or SD card to acquire georeferenced digital return information. Visual recording of depth, habitat and bottom features in the river, harbor and nearshore areas were recorded via Humminbird side-scan sonar unit. Hydroacoustic sample logs or data sheets recorded date, locations or transects sampled, and gear/frequency used. After the transect surveys had been completed for the day, daily downloads and digital copies of pinging data were made for archiving, post-processing and analysis, summarizing of data, and (later) production of mapping products for project and external use. Analysis and presentation software from Dr. Depth and DeepView FV, version 3.0 was employed to analyze and report out the side-scan data collected.

Statistical analyses and summaries of abiotic and biotic data collected were completed using SAS statistical analysis software and features of SAS Graph, Microsoft Excel and Microsoft PowerPoint. Metadata describing data collections and analysis programs are included with the databases and data/report products provided with the final report. Photographs of study areas, methods and equipment deployed, and collection observations are also included with the final report data files. Contact the PI for specific public data, program or product requests.

Results

Water levels and flow rates

Lake Erie water levels during the study period exhibited seasonal variability, but the overall trend was for average to slightly higher than average water levels when compared to long-term trends (571 ft IGLD; Figures 5a-d). The NOAA station in Cleveland did record sharp changes in water levels associated with storm and seiche events, as evidenced by the spikes (see the spike associated with Superstorm Sandy in the end of October 2012, Figure 5b) recorded in the graphs.

Water levels and flow rates varied seasonally, but overall trends and water levels recorded were very different in 2011 and 2012 based on regional climatic and precipitation patterns. The first field year (2011; Figure 5a) was characterized as a wet, cool year with much higher precipitation patterns occurring during the spring, summer and fall. Lake Erie water levels rose to almost two feet over the long-term average during the summer of 2011 and flow rates in the Cuyahoga River approached or exceeded record daily maximum flows for several days over the course of the year. The second field year (2012; Figure 5b) was characterized by a mild winter and early warm-up followed by a dry spring and summer with low precipitation and flow rates. As the second field season closed in late October and early November 2012, Superstorm Sandy ravaged the area for several days with heavy rains, hurricane-force winds, and 20-foot waves were sustained nearshore. Impacts were seen throughout the watershed, but the effects were especially detrimental to marinas and breakwalls along the Cleveland coastline: boats and docks were sunk, breakwalls were mangled, and sediment and flotsam was strewn everywhere.

Flow rates in the Cuyahoga River were relatively lower throughout 2012 compared to 2011, but passing storm events like Sandy did cause high-flow events in the watershed. There were far more times during 2011 when the flow rates were above the median daily flow rates for the time period. The USGS gauging stations in Independence (middle river location within the GLRI project study area) and Newburgh Heights (in the ship channel section of the lower river within the GLRI project area) monitored the hourly change in water levels, flow rates, and select water quality parameters (Figures 6a and 6b, and water quality parameters discussed in a later section in this report). The Newburgh Heights station is affected by barge and ship traffic in the dredged navigational channel. Flow readings are therefore less volatile and can be negative due to ships.

During 2013 and 2014, there were several extreme water events that caused change in typical flow rates in the Cuyahoga River (Figures 6c and 6d). Data from two USGS gaging stations: one located at Independence well above the ship channel at river mile 13.1, and one at Newburgh Heights, immediately above the ship channel at river mile 5.7, provide flow data on regular intervals (currently 30-min for Independence and 10-min for Newburgh Heights; all parameters measured in the project Study Area during the study period and comparisons to the Grand River gage station are presented in Appendix 1).

A couple of significant differences between the two Cuyahoga stations were noted. Flow rates at the USGS station at Independence are more “flashy” and experience longer periods of higher flows, whereas the Newburgh Heights Station appears to have shorter time period incidents of high flows. Also of concern are the effects of shipping, dredging, and lake level influence on the Newburgh Heights station resulting in periods of negative flow rates. There were multiple events of negative flow rates recorded at Newburgh heights, and none at Independence. The Grand River, in comparison also has similar swings in flow rates associated with regional storm events or weather trends (Appendix 1). However, the Grand River did have a greater frequency of periods with higher flows: the Grand approached or exceeded 10,000 cfs on five occasions during the study period, while the Cuyahoga at Independence only recorded two events in the same period.

Stream velocity readings were taken at the USGS Newburgh Heights gage station (Figure 7). Stream velocities recorded included negative values – recording upstream movement of flow. In our study, we also used a portable flow meter at various stations throughout the Cuyahoga River ship channel and were compared to velocity data gathered in the Grand River at similar (dredged, un-dredged) locations. Stream velocity rates were generally lower in the Cuyahoga River ship channel stations closer to the river mouth (Table 2), and velocities recorded at Cuyahoga stations were lower than similar stations recorded on the Grand River (dredged, undredged stations - similar comparisons). High degrees of variability within a station, and small sample sizes make statistical testing and significance difficult to determine.

Direct observations of current velocity was measured behind large ships transiting the river, recording stream velocities from propeller wash and bow, side and aft thrusters. These observations showed maximum stream velocities at distances of 10-20m from the ship ranging from 6 to 8 feet per second, compared to ambient stream velocities in the range of 0.1-2 feet per second. These extreme velocities were episodic in nature, and occurred at specific pinch points in the river where these large vessels had to maneuver in tight operating conditions: at river bends, ship passage points, bridge openings, and docking facilities. These high velocities were also observed to move volumes of water counter to normal river flow at angles ranging from oblique (perpendicular to normal flow) to upstream. The pressure waves from large ship activities were then observed to reverberate in the narrow channel, due in part to the hardened shoreline of vertical steel sheet-pile (or other hard materials like concrete) walls. This flow displacement energy took several minutes to dissipate completely. This could, in part, be the cause of negative discharge flow and stream velocity rates observed at the Newburgh Heights gage station (Figure 7).

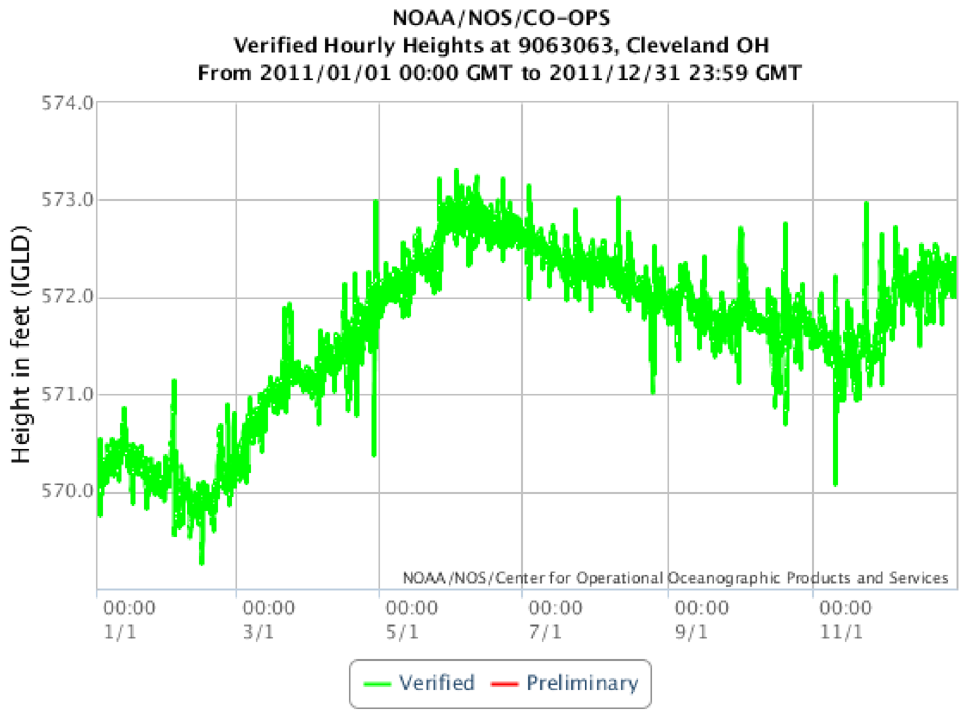


Figure 5a. Lake Erie water level height, in feet measured against the International Great Lakes 1985 Datum (IGLD), from the Cleveland Station in 2011.

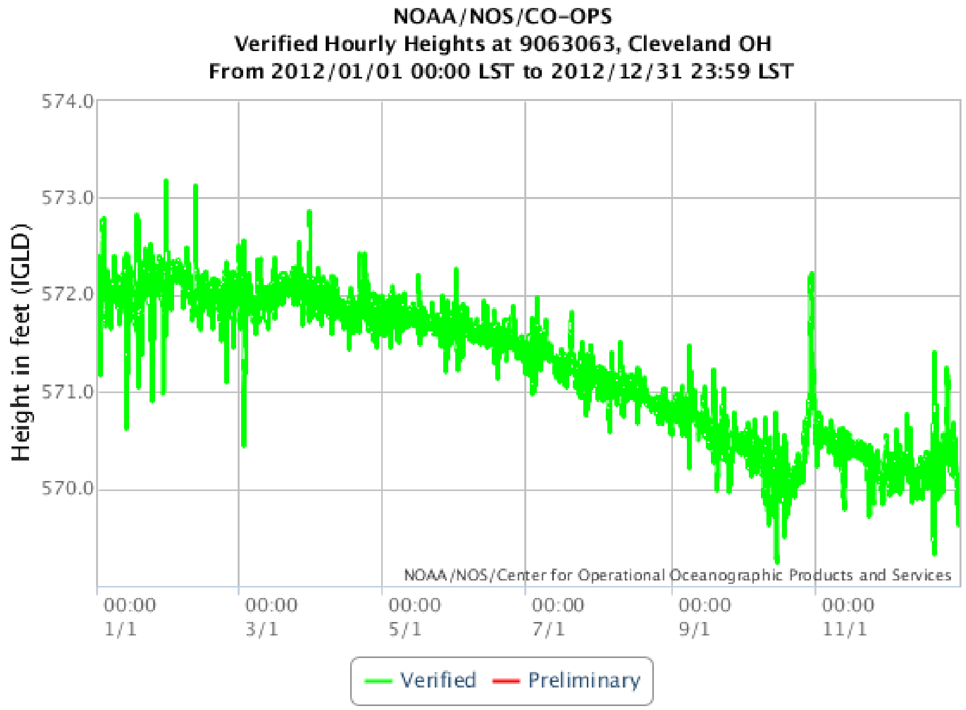


Figure 5b. Lake Erie water level height, in feet, measured against the International Great Lakes 1985 Datum (IGLD), from the Cleveland Station in 2012.

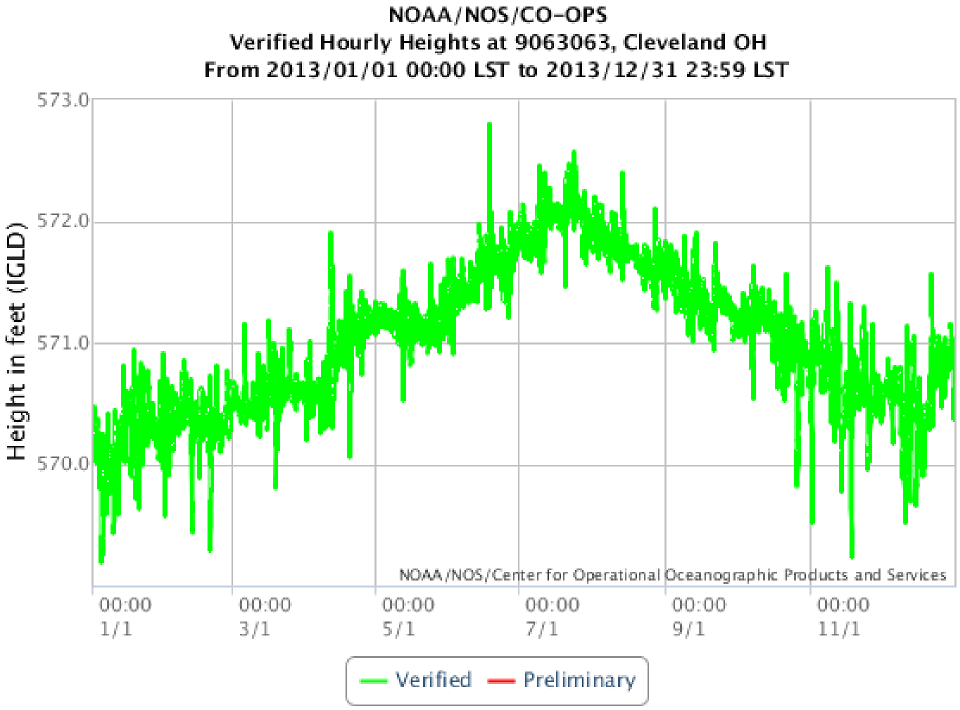


Figure 5c. Lake Erie water level height, in feet, measured against the International Great Lakes 1985 Datum (IGLD), from the Cleveland Station in 2013.

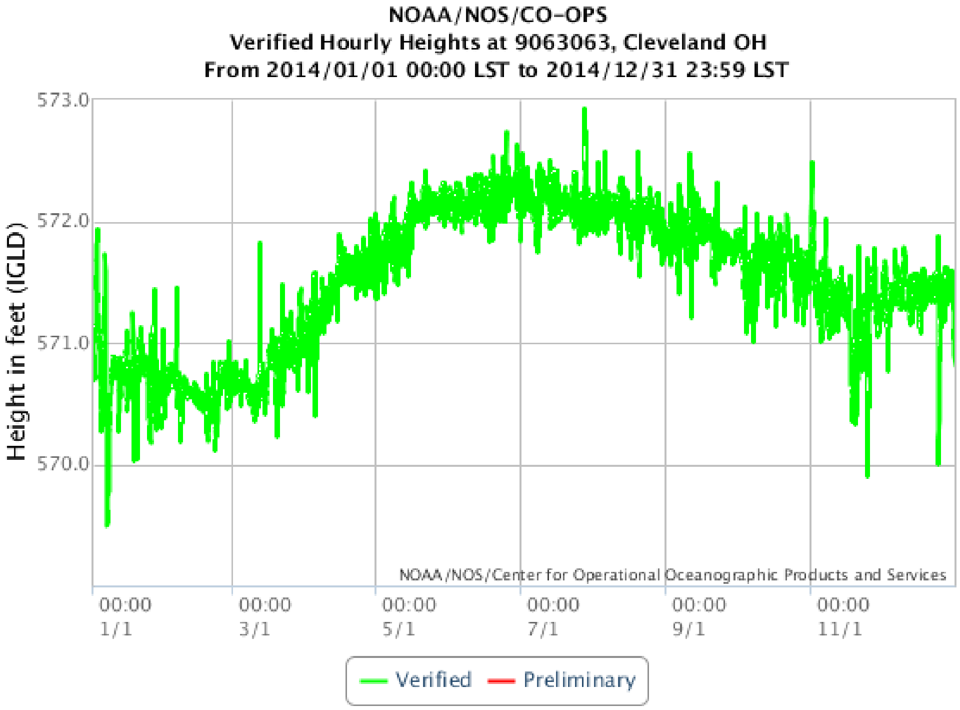


Figure 5d. Lake Erie water level height, in feet, measured against the International Great Lakes 1985 Datum (IGLD), from the Cleveland Station in 2014.

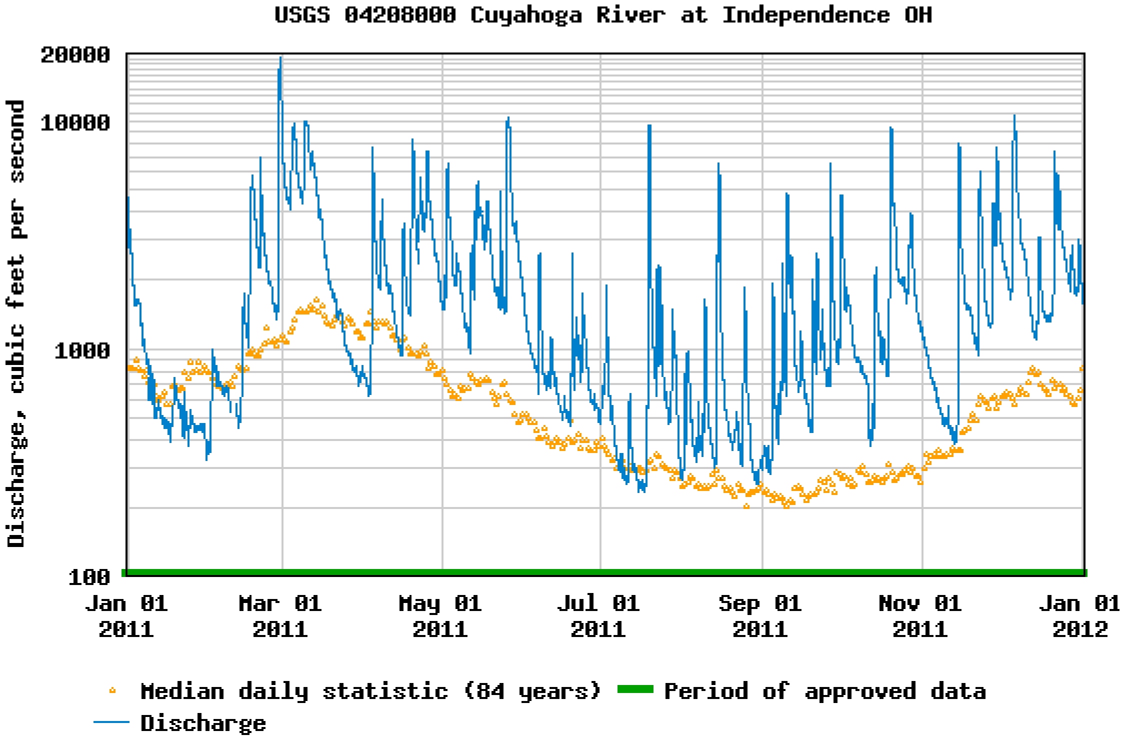


Figure 6a. USGS gaging station recording of flow rates, measured as discharge in cubic feet per second, at Independence on the Cuyahoga River for 2011.

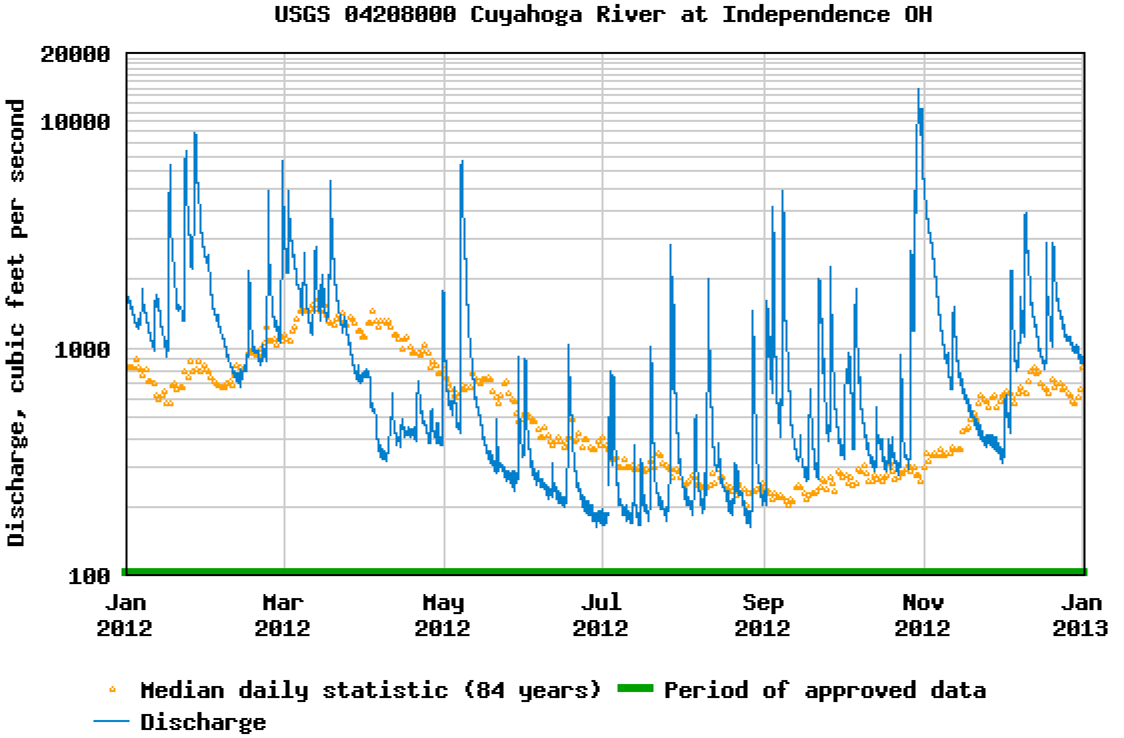
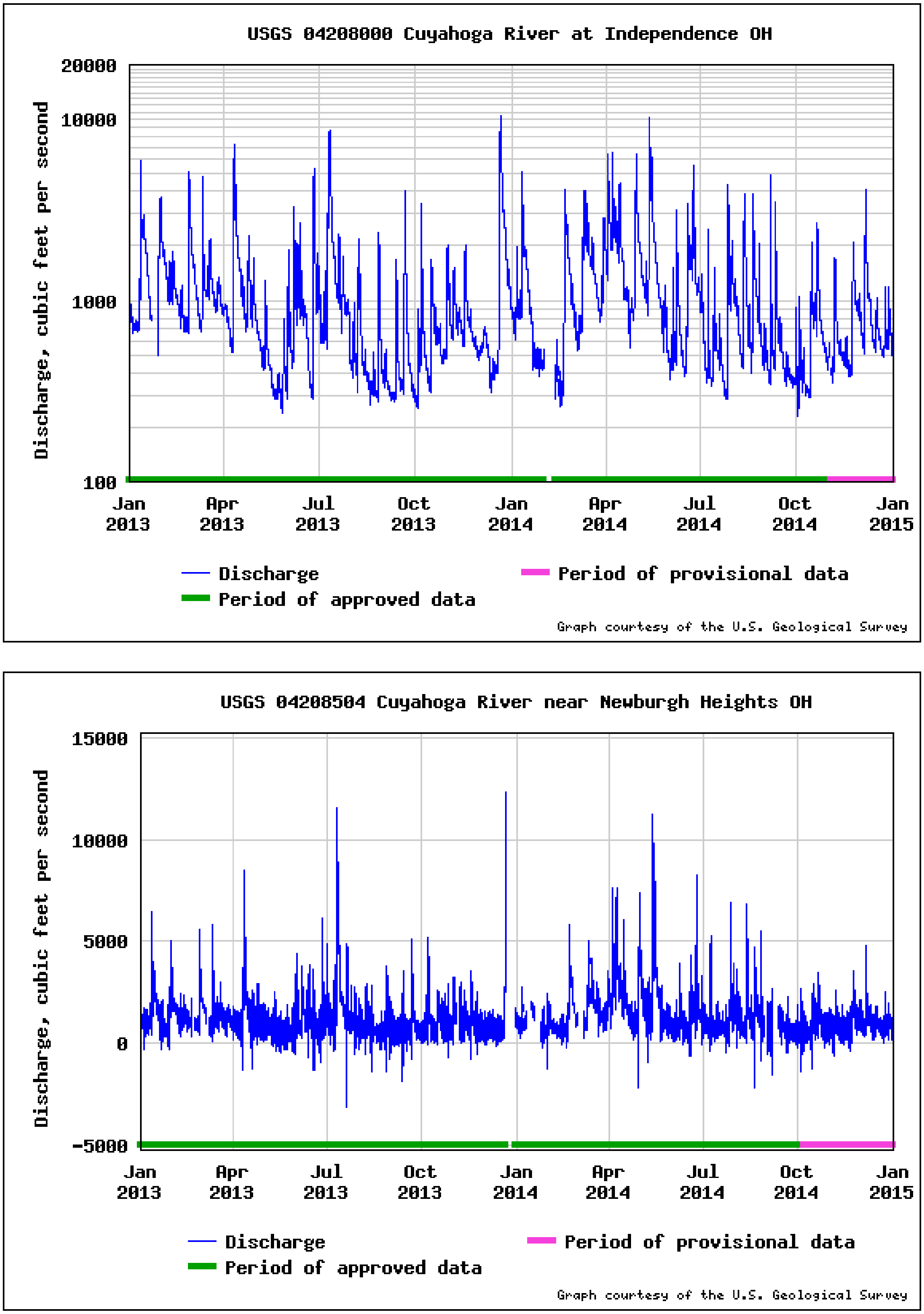


Figure 6b. USGS gaging station recording of flow rates, measured as discharge in cubic feet per second, at Independence on the Cuyahoga River for 2012.



Figures 6c and 6d. USGS gaging stations recording of flow rates, measured as discharge in cubic feet per second, at Independence and Newburgh Heights on the Cuyahoga River.

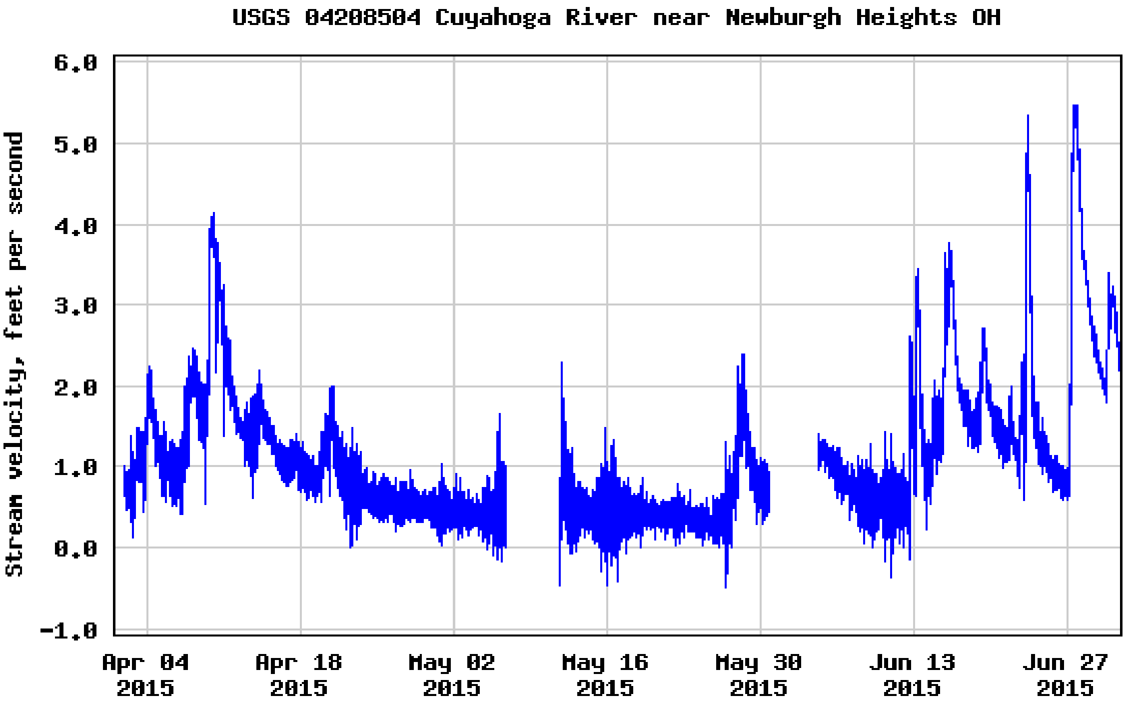


Figure 7. USGS gaging station recordings of stream velocity, in feet per second, from the Newburgh Heights station just above the Cuyahoga River ship channel, recorded during early 2015.

Tables 2a and 2b. Cuyahoga River and Grand River stream velocities measured with the Xylem FP211 meter.

Cuyahoga River measured stream velocities.

Date	Time	Station	LatDeg	LonDeg	Flow Rate
5/20/2014	1038	LR0	41.4542	81.6839	2.0 ft/sec
5/20/2014	1120	LR1	41.4651	81.6755	0.2 ft/sec
5/20/2014	1240	LR2	41.4884	81.6935	0.2 ft/sec
5/20/2014	1340	LR2itb	41.4896	81.7039	0.6 ft/sec
5/30/2014	1025	LR1	41.4649	81.6759	0.4 ft/sec
5/30/2014	1210	LR2	41.4881	81.6933	0.0 ft/sec
5/30/2014	1255	LR2itb	41.4889	81.7030	0.0 ft/sec
9/5/2014	1037	LR2	41.4880	81.6932	0.5 ft/sec
9/5/2014	1154	LR1	41.4651	81.6747	0.1 ft/sec
9/5/2014	1210	LR0	41.4640	81.6796	1.0 ft/sec
9/5/2014	1340	OC1	41.4976	81.7112	0.2 ft/sec
9/18/2014	1135	LR0	41.4542	81.6839	0.4 ft/sec
9/18/2014	1155	LR1	41.4651	81.6746	0.2 ft/sec
9/18/2014	1233	LR2	41.4880	81.6933	0.1 ft/sec
9/18/2014	1300	LR2itb	41.4893	81.7037	0.1 ft/sec
9/18/2014	1325	OC1	41.4968	81.7126	0.1 ft/sec
5/27/2015	1345	LR0	41.4541	81.6838	1.9 ft/sec
5/27/2015	1410	LR1	41.4647	81.6762	0.8 ft/sec
5/27/2015	1453	LR2	41.4884	81.6933	0.3 ft/sec

Grand River measured stream velocities.

Date	**Time**	**Station**	**LatDeg**	**LonDeg**	**Flow rate**
5/19/2014	1420	GR2	41.7529	81.2803	0.1 ft/sec
5/19/2014	1510	GR1	41.7390	81.2634	1.7 ft/sec
6/4/2014	930	GR2	41.7522	81.2803	0.2 ft/sec
6/4/2014	1025	GR1	41.7415	81.2623	0.6 ft/sec
7/2/2014	937	GR2	41.7532	81.2802	0.2 ft/sec
7/2/2014	1038	GR1	41.7418	81.2627	0.2 ft/sec
9/2/2014	1348	GR2	41.7532	81.2802	0.4 ft/sec
9/2/2014	1457	GR1	41.7420	81.2628	0.4 ft/sec
9/17/2014	1130	GR2	41.7526	81.2799	1.0 ft/sec
9/17/2014	1220	GR1	41.7418	81.2629	0.0 ft/sec
9/30/2014	1415	GR2	41.7523	81.2800	0.1 ft/sec
9/30/2014	1525	GR1	41.7418	81.2628	0.5 ft/sec
11/4/2014	935	GR2	41.7530	81.2800	0.1 ft/sec
11/4/2014	1025	GR1	41.7420	81.2629	0.1 ft/sec
4/28/2015	1510	GR1	41.7419	81.2629	0.2 ft/sec
4/28/2015	1555	GR2	41.7515	81.2803	0.0 ft/sec
5/26/2015	945	GR1	41.7422	81.2630	0.5 ft/sec
5/26/2015	1030	GR2	41.7516	81.2802	0.4 ft/sec

Water chemistry signatures; BGSU contract reports.

Water samples were obtained from study area locations in 2011 and 2012 for elemental isotope analyses (Tables 3a and 3b). Ludsin (2006) and Miner et al. (2010) have shown that watersheds may contain unique concentrations and/or ratios of elemental isotopes such as strontium, barium, calcium and manganese, thus imparting a signature for natal streams or habitats. These unique signature concentrations of elements are then incorporated into fish hard structures such as otoliths during early life history, essentially imparting unique markers on different fish stocks in different natal habitats or locations. Using techniques such as laser oblation on otoliths extracted from juvenile or adult fish, these unique chemical signatures can be identified and fish can be traced back to their natal origin. This method has been explored for several species and in limited locations in Lake Erie.

Water sample analysis was completed and results provided by Dr. Jeffery Miner of Bowling Green State University who is building a database catalogue of the values from Lake Erie, Ohio streams, and state fish hatcheries locations around Lake Erie. This work has added to the Lake Erie database of similar elemental and otolith microchemistry studies.

Comparisons can be made to Boehler (2010) and Hayden (2009) studies that collected water chemistry data for specific isotopes to identify fish stocks in Lake Erie. The Cuyahoga River and Cleveland harbor water samples did not have significantly different concentrations of elemental isotopes that would allow us to identify these waters as unique as far as fish production. Concentrations of barium, calcium, magnesium and strontium overlapped those results seen in other parts of Lake Erie, particularly mimicking the ranges observed by Hayden (2009) for the open waters of the western basin of Lake Erie (Table 3c). Values for Maumee Bay and Sandusky Bay for elements other than strontium were also similar to those collected in the Cuyahoga River. The overlapping in these concentration ranges meant that we could not complete otolith analysis that would result in discrete assignment back to the Cuyahoga River or Cleveland harbor water source at this time. Assignment and analysis techniques may be developed in the near future that could improve this technique.

Water quality parameters

Water samples were taken daily during routine field sampling events at sites in the Cuyahoga, Cleveland Harbor, outer breakwall during 2011-2014 and in comparison the Grand River during 2013 and 2014 to ascertain *in situ* conditions and trends or changes in water quality and aquatic habitat (Tables 4a-d). Results for each parameter are presented and discussed below.

Table 3a and 3b. Elemental analysis of water samples taken at Study Area stations during spring 2011 and 2012. Concentrations are reported in parts per million.

2011

Element	MDL	OB1	OB2	H1	H2	OC1	LR1	LR2	MR1[a]	MR2	TC1
Ba	0.0003	0.0159	0.0161	0.0199	0.0292	0.0301	0.0303	0.0271	--	0.0303	0.0287
Ca	0.0245	26.7800	25.7100	28.9800	33.9500	31.1000	36.8100	30.6200	--	34.2300	38.7400
Cd	0.0005	*	*	*	*	*	*	*	--	*	*
Co	0.0009	*	*	0.0003	0.0003	0.0014	*	0.0006	--	0.0001	0.0002
Cr	0.0020	*	*	*	*	*	*	*	--	*	*
Cu	0.0015	0.0064	0.0035	0.0026	0.0292	0.0060	0.0047	0.0041	--	0.0031	0.0031
Fe	0.0016	0.3648	0.1329	0.5445	0.8709	1.7680	1.1620	1.1670	--	0.9448	0.6859
K	0.0131	1.9880	1.9520	2.6140	3.9960	3.8960	3.8530	3.6900	--	3.2070	3.2570
Mg	0.0123	7.7790	7.6680	8.3300	8.7530	7.5440	8.9240	7.2930	--	8.2300	8.7640
Mn	0.0004	0.0054	0.0022	0.0154	0.0471	0.0773	0.0593	0.0415	--	0.0524	0.0928
Mo	0.0015	0.0015	0.0026	0.0022	0.0029	0.0024	0.0025	0.0027	--	0.0025	0.0033
Na	0.3387	14.5800	12.5800	28.1000	51.5900	65.4800	57.5600	54.4500	--	54.7400	78.0400
Ni	0.0011	0.0006	0.0002	0.0015	0.0032	0.0039	0.0035	0.0024	--	0.0015	0.0019
Pb	0.0047	0.0065	0.0084	0.0097	0.0221	0.0125	0.0116	0.0121	--	0.0099	0.0092
Sr	0.0001	0.1649	0.1676	0.1946	0.1683	0.1540	0.1618	0.1458	--	0.1403	0.2282
Zn	0.0004	*	*	*	*	*	*	*	--	*	*

All values in ppm

a - location MR1 not sampled in 2011

* = below minimum detection limit (MDL)

2012

Element	MDL	OB1	OB2	H1	H2	OC1	LR1	LR2	MR1	MR2	TC1
Ba	0.0002	0.0170	0.0145	0.0237	0.0155	0.0321	0.0404	0.0440	0.0441	0.0439	0.0412
Ca	0.0575	34.8200	32.1900	41.2100	33.0200	51.1700	70.3600	64.0400	72.5800	72.3100	72.6700
Cd	0.0009	*	*	*	*	*	*	*	0.0022	*	*
Co	0.0023	*	*	*	*	*	*	*	*	*	*
Cr	0.0037	*	*	*	*	*	*	*	*	*	*
Cu	0.0038	*	*	*	*	*	*	*	*	*	0.0043
Fe	0.0032	0.0081	0.0056	0.0106	0.0070	0.0166	0.0278	0.0201	0.0151	0.0129	0.0435
K	0.0195	1.9900	1.5230	2.9550	1.7170	4.7120	8.1060	6.3710	5.3110	5.6170	7.1390
Mg	0.0334	8.7520	8.3460	9.9510	8.5130	11.5100	16.8200	14.8100	16.3200	16.4900	17.2000
Mn	0.0005	0.0056	*	0.0302	0.0005	0.0535	0.0591	0.0047	*	0.0343	0.0179
Mo	0.0074	*	*	*	*	*	0.0081	*	*	*	*
Na	0.0067	20.3000	12.2000	39.6000	16.0000	92.3000	109.1000	93.0000	93.0000	100.2000	143.3000
Ni	0.0022	*	*	*	0.0025	*	0.0046	0.0024	*	*	*
Pb	0.0149	*	*	*	*	*	*	*	*	*	*
Sr	0.0001	0.1593	0.1544	0.1751	0.1557	0.2234	0.2474	0.2283	0.2520	0.2266	0.3504
Zn	0.0010	0.0220	0.0094	0.0047	0.0052	0.0378	0.0142	0.0356	0.2397	0.0106	0.0180

All values in ppm

* = below minimum detection limit (MDL)

Table 3c. Comparisons of elemental isotopes from water samples (ppb) in the Cuyahoga River to open water Lake Erie samples acquired by Hayden (2009).

Location	Ba	Ca	Mg	Sr	Sr:Ca
Hayden - West basin Lake Erie					
S of West Sister Island	155	32084	9185	135	0.0042
N of West Sister Island	149	29970	8742	117	0.0039
Inner Maumee Bay	174	57054	15986	569	0.0100
Outer Maumee Bay	160	39712	11664	321	0.0081
Maumee Bay approach offshore	149	34930	10352	207	0.0059
NW of West Sister Island	106	27544	7963	89	0.0032
Outside Detroit River	141	26960	7941	82	0.0030
SW of S Bass Island	145	32176	9062	142	0.0044
W of N Bass Island	143	34930	8856	133	0.0038
W of Hen and Chicks Islands	131	29044	8456	102	0.0035
In Sandusky Bay	154	51226	15176	991	0.0193
Offshore Sandusky sub-basin	147	32626	8976	130	0.0040
Nearshore off Cedar Point	143	33876	9409	182	0.0054
Cuyahoga River					
OB1 - west open water	165	30800	8266	162	0.0053
OB2 - east open water	153	28950	8007	161	0.0056
H1 - west harbor	218	35095	9141	185	0.0053
H2 - east harbor	224	33485	8633	162	0.0048
OC1 - upper Old Channel	311	41135	9527	189	0.0046
LR1 - near Head of Nav channel	354	53585	12872	205	0.0038
LR2 - lower river, near I-90	356	47330	11052	187	0.0040
MR1 - middle river, Rt 82 dam	441	72580	16320	252	0.0035
MR2 - middle river, Rockside Rd.	371	53270	12360	183	0.0034
TC1 - Tinkers Creek at mouth	350	55705	12982	289	0.0052

Table 4a. GLRI project monitoring parameters and activity dates from 2011. Abbreviations: Temp – water temperature; DO – dissolved oxygen; ZP – zooplankton; PP – phytoplankton; chl *a* – chlorophyll a; SRP – soluble reactive phosphorus; IP –ichthyoplankton/ larval fish sampling.

Location	Temp/DO	Secchi	Light	ZP/PP	Chl *a*, SRP	IP	Benthos
Cuyahoga River, Harbor, and Outer Breakwall	4/14, 4/21, 5/4&5, 5/10, 5/19, 5/25, 6/2, 6/15, 6/30, 7/18, 7/27, 8/11, 8/19, 9/12, 9/29, 10/25, 10/28, 11/18	4/14, 4/21, 5/4&5, 5/10, 5/19, 5/25, 6/2, 6/15, 6/30, 7/18, 7/27, 8/11, 8/19, 9/12, 9/29, 10/25, 10/28, 11/18	4/14, 4/21, 5/4&5, 5/10, 5/19, 5/25, 6/2, 6/15, 6/30, 7/18, 7/27, 8/11, 8/19, 9/12, 9/29, 10/25, 10/28, 11/18	5/4, 5/10, 5/19, 5/25, 6/2, 6/15, 6/30, 7/18, 7/27, 8/11, 8/19, 9/12, 9/29, 10/25, 10/28, 11/18	4/14, 4/21, 5/4&5, 5/10, 5/19, 5/25, 6/2, 6/15, 6/30, 7/18, 7/27, 8/11, 8/19, 9/12, 9/29, 10/28	4/21, 5/4&5, 5/10, 5/19, 5/25, 6/2, 6/15, 6/30, 7/18, 8/11, 9/12	7/27&28, 9/29

Table 4b. GLRI project monitoring parameters and activity dates from 2012.

Location	Temp/DO	Secchi	Light	ZP/PP	Chl *a*, SRP	IP	Benthos
Cuyahoga River, Harbor, and Outer Breakwall	4/19, 5/2, 5/15, 5/24, 5/30, 6/6&8, 6/15, 6/28, 7/10&12, 7/25, 7/30, 8/7, 8/22, 9/7, 9/20, 10/9	4/19, 5/2, 5/15, 5/24, 5/30, 6/6&8, 6/15, 6/28, 7/10&12, 7/25, 7/30, 8/7, 8/22, 9/7, 9/20, 10/9	4/19, 5/2, 5/15, 5/24, 5/30, 6/6&8, 6/15, 6/28, 7/10&12, 7/25, 7/30, 8/7, 8/22, 9/7, 9/20, 10/9	4/19, 5/2, 5/15, 5/30, 6/15, 6/28, 7/10&12, 7/25, 8/7, 8/22, 9/7, 9/20, 10/9	4/19, 5/2, 5/15, 5/24, 5/30, 6/6&8, 6/15, 6/28, 7/10&12, 7/25, 7/30, 8/7, 8/22, 9/7, 9/20, 10/9	5/2, 5/15, 5/24, 5/30, 6/6&8, 6/15, 6/28, 7/10&12, 7/25, 8/7, 8/22	7/30

Table 4c. GLRI project monitoring parameters and activity dates for 2013.

Location	Temp/DO	Secchi	Light	ZP/PP	Chl *a*, SRP	IP	Benthos
Cuyahoga River and Harbor	4/18, 4/26, 5/9, 5/16, 5/30, 6/24, 7/9, 7/26, 8/7, 8/22, 9/5, 9/10, 9/16, 10/2, 10/18	4/18, 4/26, 5/9, 5/16, 5/30, 6/24, 7/9, 7/26, 8/7, 8/22, 9/5, 9/10, 9/16, 10/2, 10/18	4/18, 5/9, 5/16, 5/30, 6/24, 7/9, 7/26, 8/7, 8/22, 9/5, 9/10, 9/16, 10/2	4/18, 5/9, 5/16, 5/30, 6/24, 7/9, 7/26, 8/7, 8/22, 9/5, 9/10, 9/16, 10/2	4/18, 5/9, 5/16, 5/30, 6/24, 7/9, 7/26, 8/7, 8/22, 9/5, 9/10, 9/16, 10/2	4/18, 4/26, 5/9, 5/16, 5/30, 6/24, 7/9, 7/26, 8/7	9/10, 9/16
Grand River	4/17, 5/8, 5/17, 5/31, 6/25, 7/8, 7/25, 8/9, 8/23, 9/6, 9/23	4/17, 5/8, 5/17, 5/31, 6/25, 7/8, 7/25, 8/9, 8/23, 9/6, 9/23	4/17, 5/8, 5/17, 5/31, 6/25, 7/8, 7/25, 8/9, 8/23, 9/6, 9/23	4/17, 5/8, 5/17, 5/31, 6/25, 7/8, 7/25, 8/9, 8/23, 9/6, 9/23	4/17, 5/8, 5/17, 5/31, 6/25, 7/8, 7/25, 8/9, 8/23, 9/6, 9/23	5/8, 5/17, 5/31, 6/25, 7/8	8/23

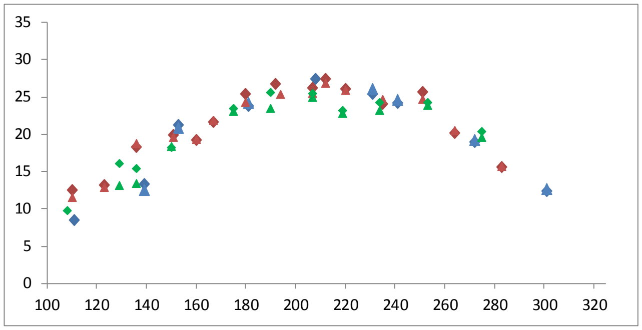
Table 4d. GLRI project monitoring parameters and activity dates for 2014.

Location	Temp/DO	Secchi	Light	ZP/PP	Chl *a*, SRP	IP
Cuyahoga River and Harbor	5/20, 5/30, 6/19,7/1, 7/22,8/8, 8/21,9/5, 9/18, 10/9, 10/22	5/20, 5/30, 6/19,7/1, 7/22,8/8, 8/21,9/5, 9/18, 10/9, 10/22	5/20, 5/30, 6/19,7/1, 7/22,8/8, 8/21,9/5, 9/18, 10/9, 10/22	5/20, 5/30, 6/19,7/1, 7/22,8/8, 8/21,9/5, 9/18, 10/9, 10/22	5/20, 5/30, 6/19,7/1, 7/22,8/8, 8/21,9/5, 9/18, 10/9, 10/22	5/20, 5/30, 6/19,7/1
Grand River	4/24, 5/19, 6/4,6/18, 7/2, 7/24, 8/5, 8/19, 9/2, 9/17, 9/30, 10/17, 11/4	4/24, 5/19, 6/4,6/18, 7/2, 7/24, 8/5, 8/19, 9/2, 9/17, 9/30, 10/17, 11/4	4/24, 5/19, 6/4,6/18, 7/2, 7/24, 8/5, 8/19, 9/2, 9/17, 9/30, 10/17, 11/4	4/24, 5/19, 6/4,6/18, 7/2, 7/24, 8/5, 8/19, 9/2, 9/17, 9/30, 10/17, 11/4	4/24, 5/19, 6/4,6/18, 7/2, 7/24, 8/5, 8/19, 9/2, 9/17, 9/30, 10/17, 11/4	4/24, 5/19, 6/4,6/18, 7/2

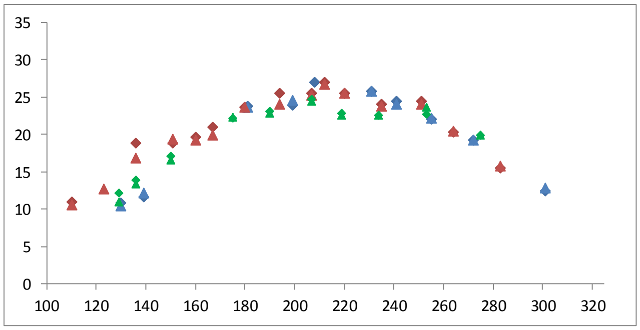
Water temperatures

During 2011-2013, we recorded water temperature profiles on the Cuyahoga River, harbor and outer breakwall sample stations (Figure 8). During 2013 and 2014, we recorded water temperature profiles on the Cuyahoga and Grand rivers at sample stations (Figures 9a and b), and during 2014 we recorded water temperatures at approximately 1m of depth through the deployed data sondes (Figure 10a-e). Both station and sonde data show seasonal and episodic variability (explained by changing seasons and weather patterns).

Station LR1h (near the old Cuyahoga County habitat project and adjacent to a major river outfall) data appears to be elevated compared to other stations. This fact is further borne out by individual temperature readings obtained while traveling in the Cuyahoga River between stations LR2 and LR1 at the head of the navigational channel (Table 5). Temperatures in this limited stretch of water ranged from more than 1 to almost 5 degrees C warmer than nearby stations. This change in temperatures could have thermal effects on larvae and juvenile fish and food distribution. Further work on the possible effects, and remediating sources of thermal inputs, is warranted.



Surface Temp in C Julian Day reference: 100= Apr 10 150= May 30
Blue=2011, Red=2012, Green=2013 200= Jul 19 250= Sep 7
Diamond=H1, Triangle=H2 300= Oct 27



Surface Temp in C
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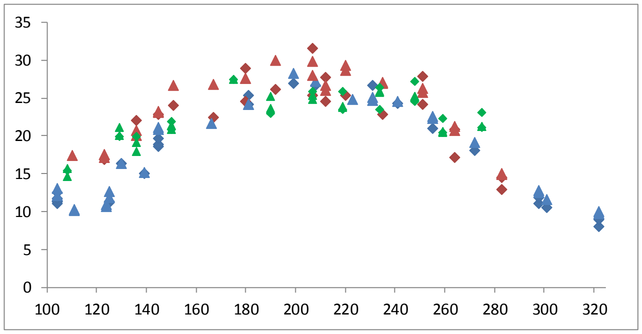
Diamond=OB1, Triangle=OB2



Surface Temp in C
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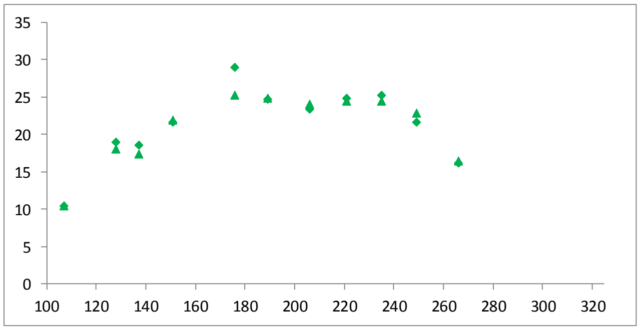
Diamond=LR1, Triangle=LR2



Surface Temp in C
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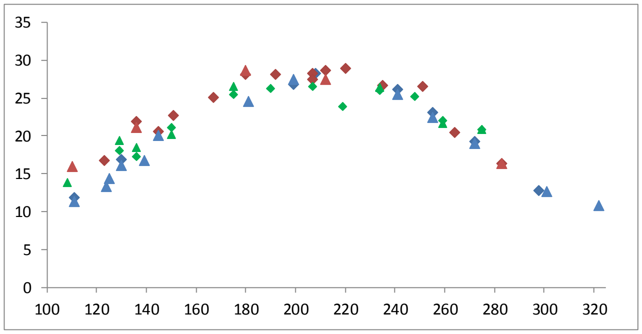
Diamond=GR1, Triangle=GR2



Surface Temp in C
Blue=2011, Red=2012, Green=2013
Diamond=OC1, Triangle=OC2

Figure 8. Surface water temperatures (in degrees Celsius) at Study Area sampling stations during 2011-2013 sample dates.

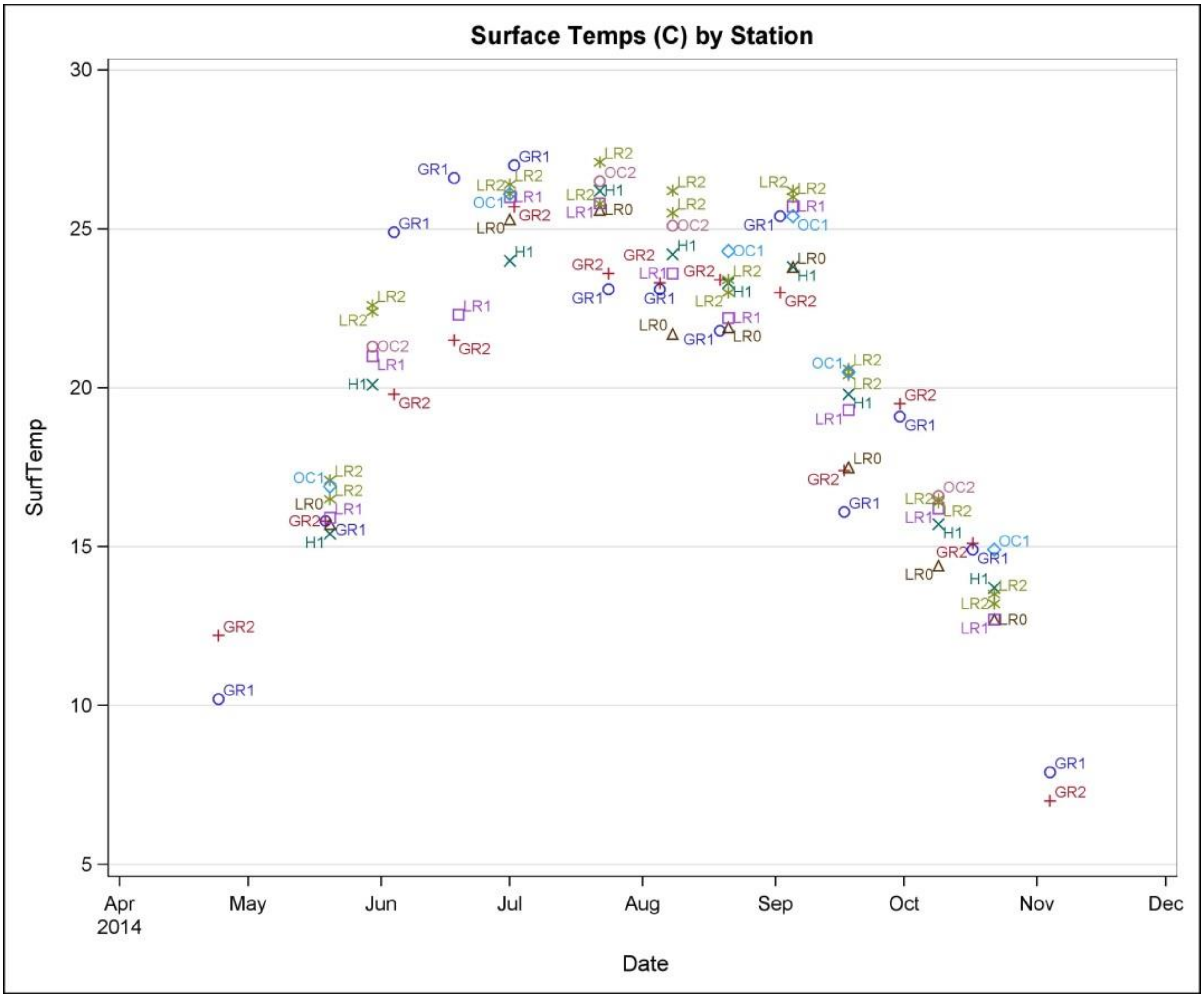


Figure 9a. Surface water temperatures at sampling stations in 2014.

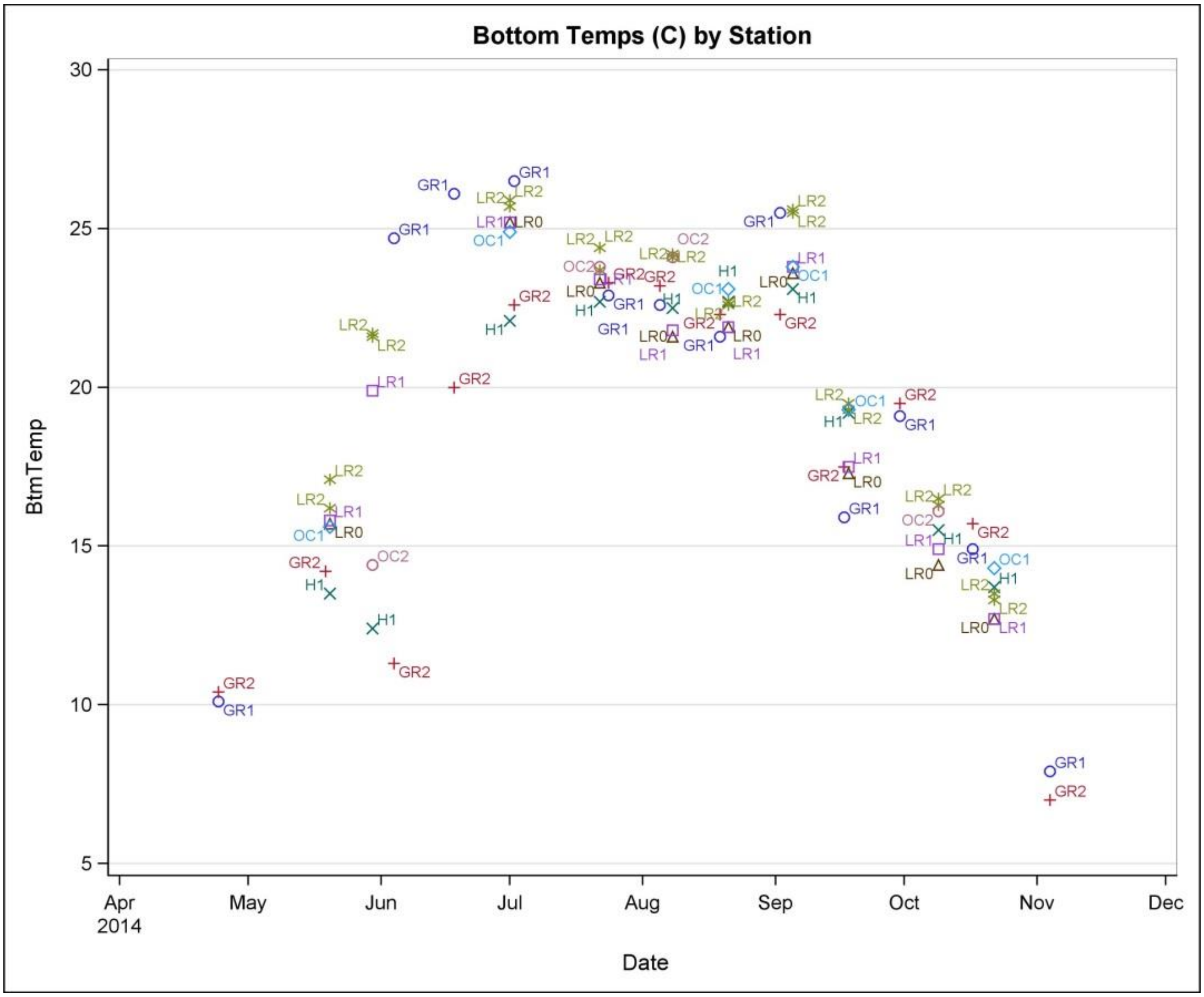
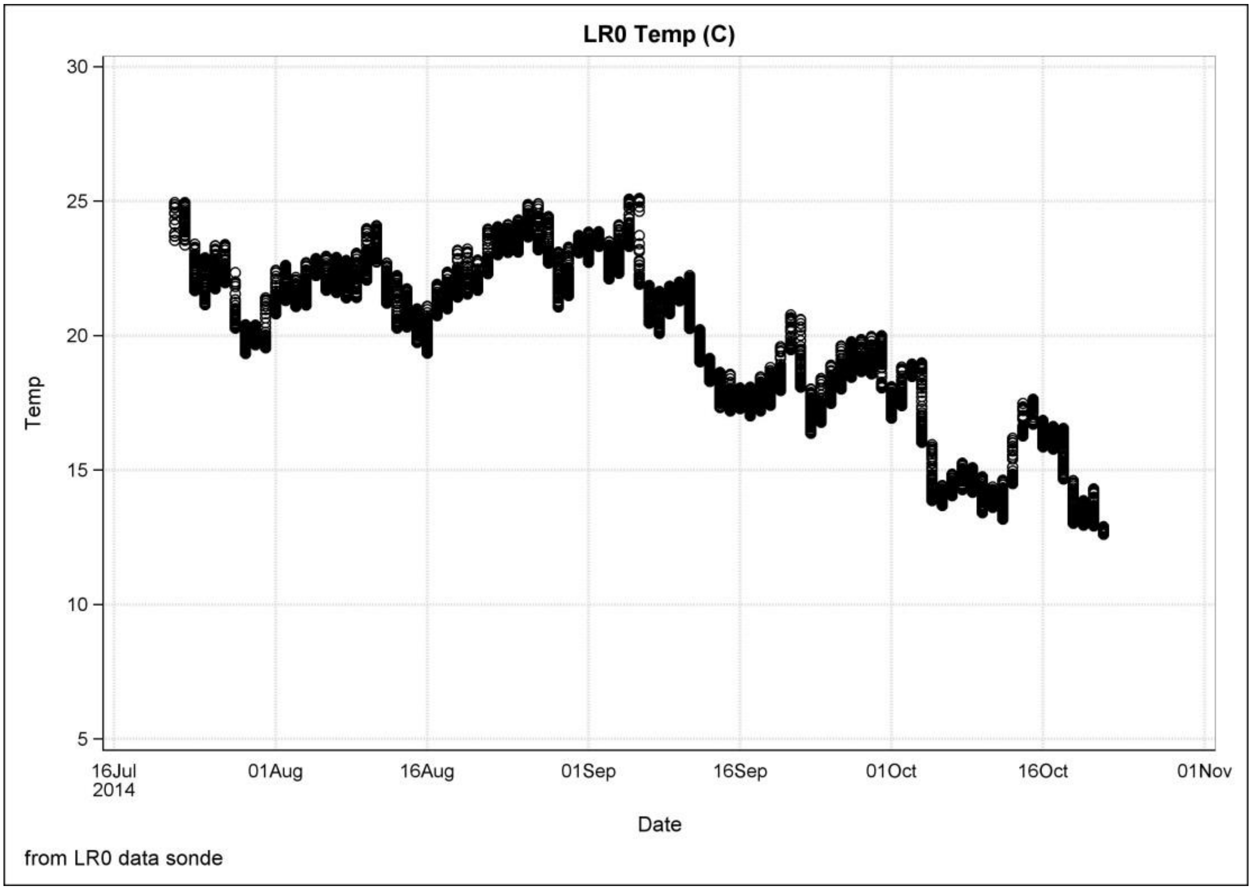


Figure 9b. Bottom water temperatures at sampling stations in 2014.



from LR0 data sonde

Figure 10a. Cuyahoga River Station LR0 (1sr riffle) water temperatures recorded from the data sonde in 2014.

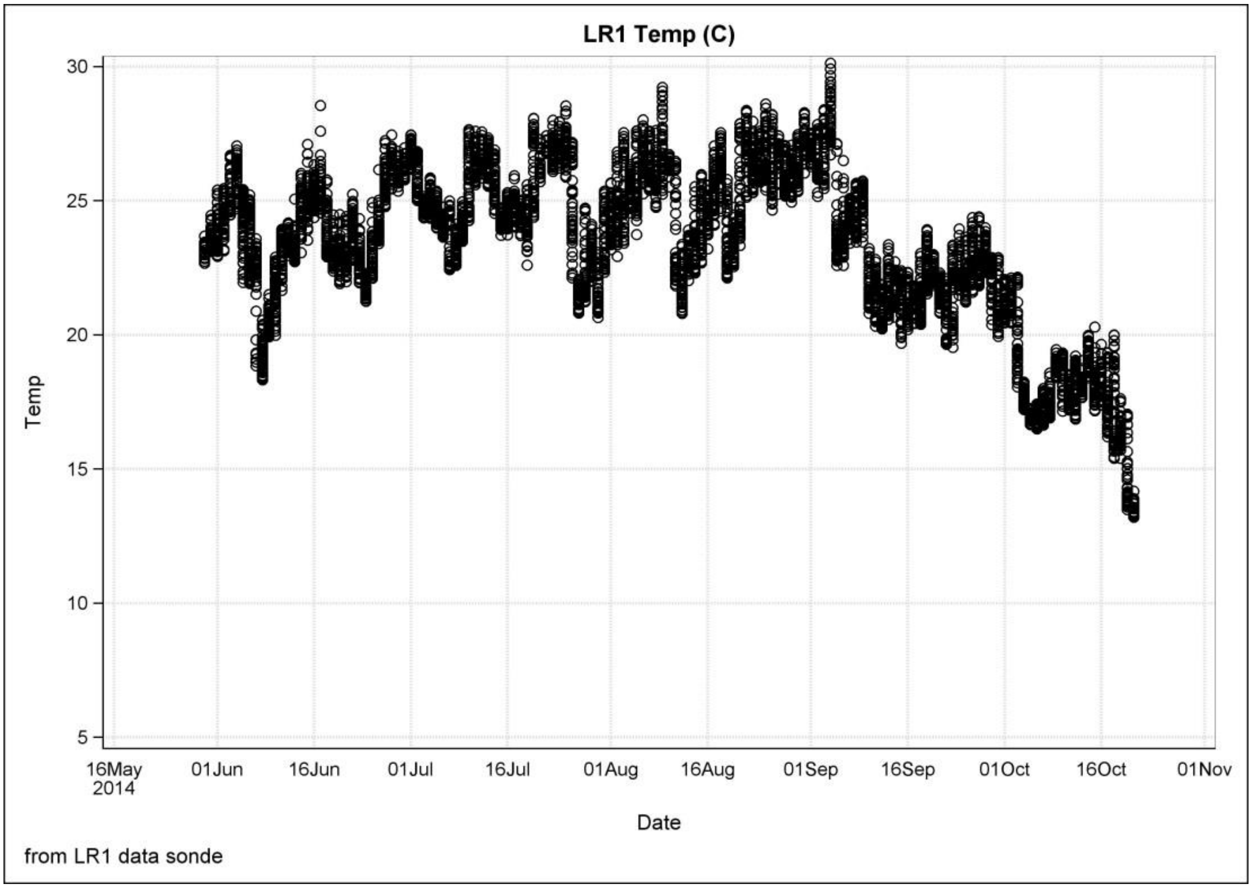


Figure 10b. Cuyahoga River Station LR1 (I-490) water temperatures recorded from the data sonde in 2014.

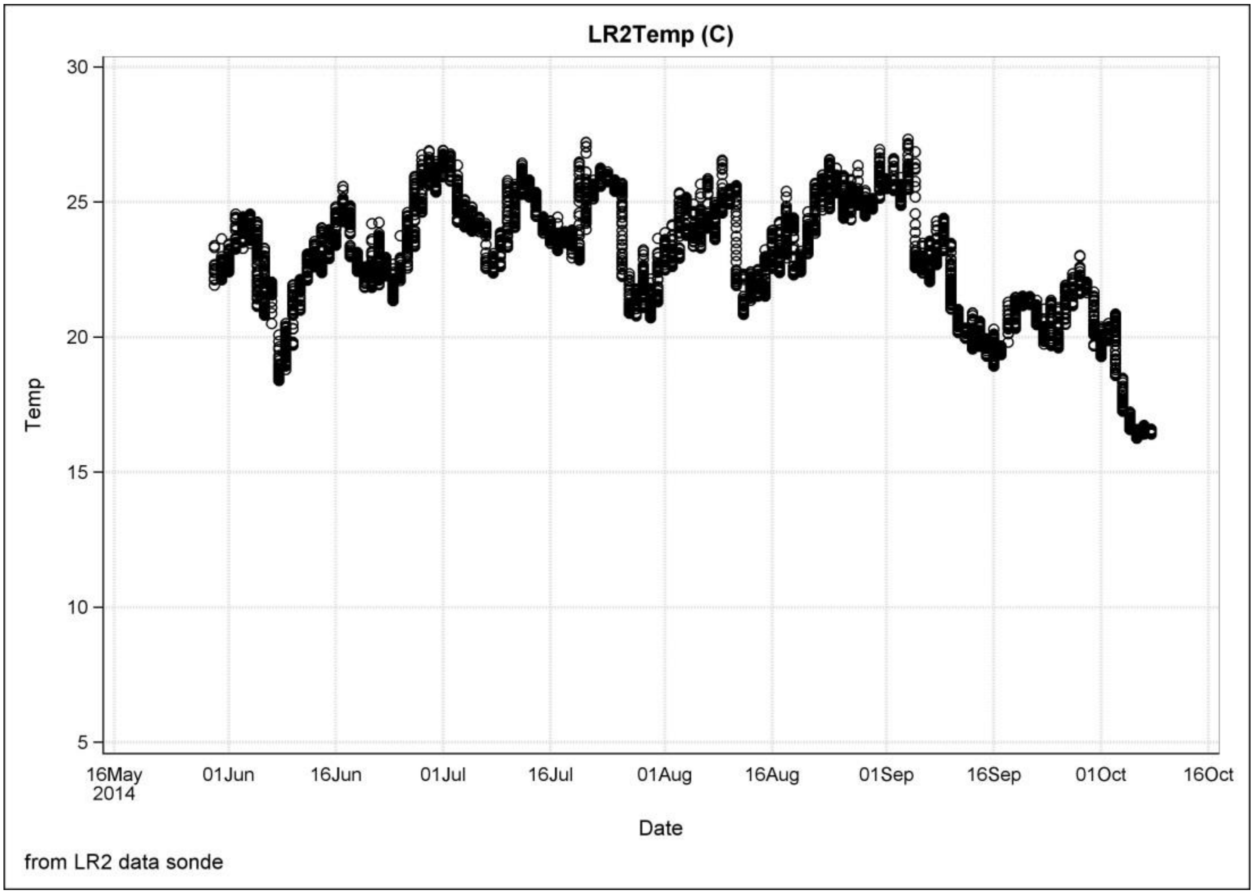


Figure 10c. Cuyahoga River Station LR2 (I-90) water temperatures recorded from the data sonde in 2014.

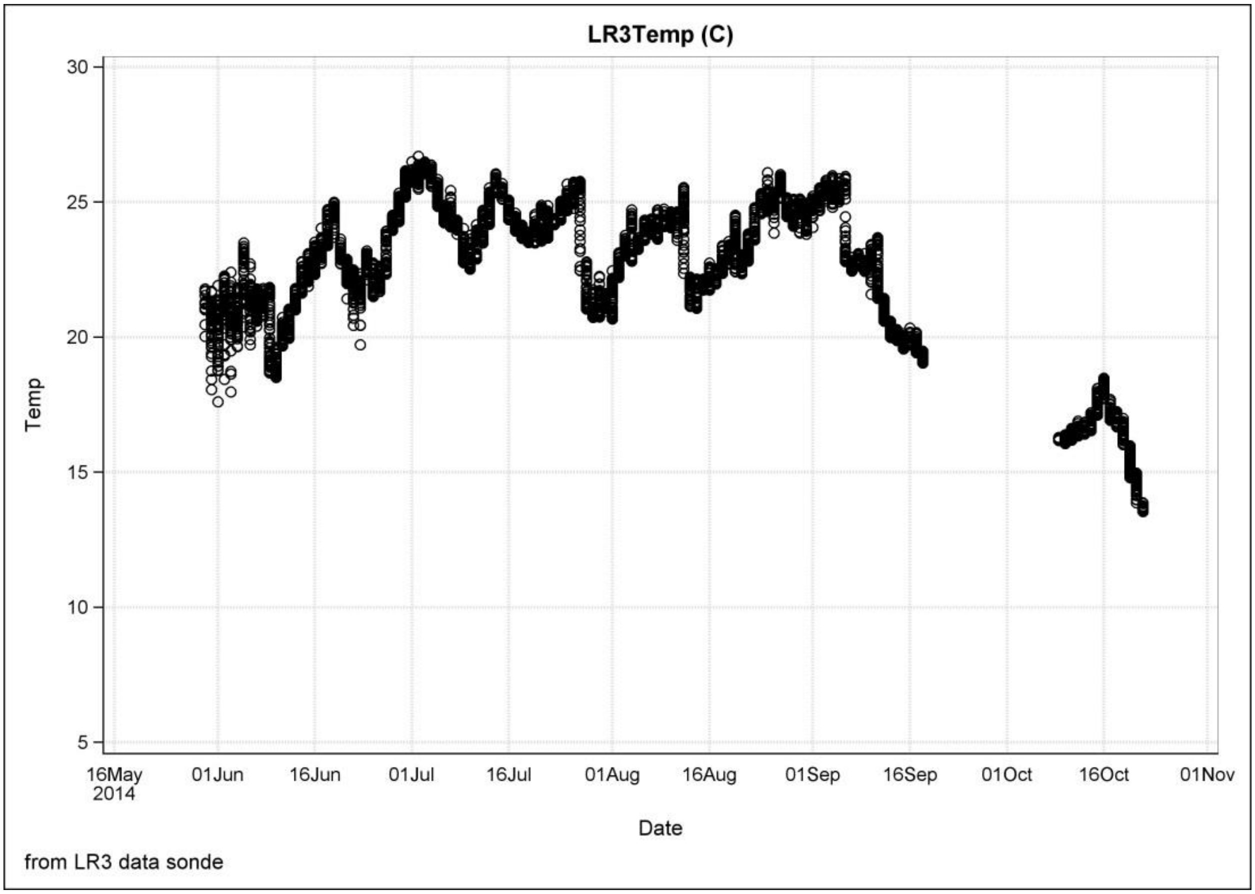


Figure 10d. Cuyahoga River Station LR3 (Samsel's) water temperatures recorded from the data sonde in 2014.

Figure 10e. Grand River Station GR2 (Grand R. Marine) water temperatures recorded from the data sonde.

Table 5. Thermal exceptions to water temperatures in the Cuyahoga River dataset.

Temperature (^{o}C)		less than 0.5 m subsurface		
Date	LR0	LR1	**LR1h**	LR2
5/30/2014	--	21.0	**25.6**	22.4
8/8/2014	21.7	23.6	**28.9**	26.2
9/18/2014	17.5	19.3	**24.6**	20.6
10/9/2014	14.4	16.5	**19.9**	16.5
10/22/2014	12.7	12.7	**14.7**	13.2
5/30/2013	--	20.9	**21.9**	21.4
6/24/2013	--	27.5	**31.1**	27.4
7/9/2013	--	23.0	**25.9**	23.6
7/26/2013	22.1	25.9	**30.0**	24.8
8/7/2013	--	23.5	**25.9**	23.9
8/22/2013	--	23.5	**26.4**	25.9
9/5/2013	21.3	24.6	**29.4**	25.2
9/16/2013	19.1	20.4	**24.2**	20.6
10/2/2013	19.4	21.1	**23.1**	21.3

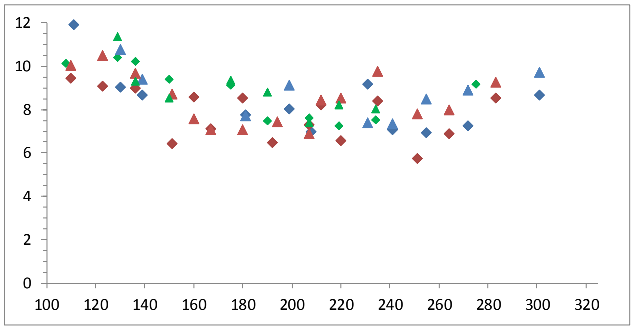
Dissolved Oxygen / %DO saturation

One of the main concerns about maintaining healthy populations of aquatic life in the Cuyahoga River ship channel has been sustaining desirable levels of dissolved oxygen. Low to anoxic DO levels have been recorded in the past, and one of the keys to restoration in this part of the river and harbor is adequate levels of DO to support aquatic life. Our research in the lower river and harbor recorded an advancement in conditions that result in improved DO readings throughout the year at nearly all sample areas. During 2011-2014, we recorded dissolved oxygen profiles on the Cuyahoga and Grand rivers at sample stations (Figures 11a-d). During May-October 2014, we recorded dissolved oxygen continuously at approximately 1m of water depth through the deployed data sondes (Figures 12a-e).

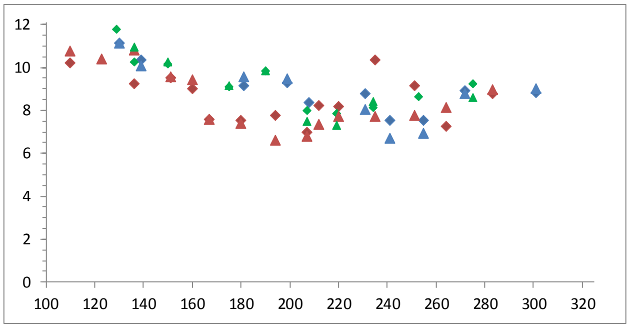
In review of our DO readings at fixed stations LR1, LR2, OC1, OC2 and GR2, there were few instances of critical DO levels below 1.5 mg/l, which is the federally designated restoration target is shipping channels (OEPA 2014). There was only one instance of surface DO below the 1.5 mg/l threshold, and that occurred at OC2 in spring of 2013. Bottom water DO readings below the critical 1.5 mg/l threshold were a bit more frequent: happening at Cleveland harbor sites four times over the three years of 2011-2013, eight times during the same three-year period at lower river ship channel sites, six times in Old Channel sites, and one time at a Grand River ship channel site. Total sampling dates ranged from a low of 34 at Old Channel sites to 64 at lower river sites, so frequency of exceedance was low to moderate by this traditional sampling method.

While we observed some variability in our sonde DO data, we did not record any anoxic conditions or conditions below the 1.5 mg/l threshold. In 2014, only one observation below 2 mg/l (at LR3 in early September) was recorded. Station LR3 did have extended periods of DO readings at 4 mg/l or below, and DO generally improved as you moved upstream beyond the dredged areas. The Grand River location (GR2) at the head of the navigational ship dredge channel behaved similarly to the head of the navigation channel in the Cuyahoga River (LR1).

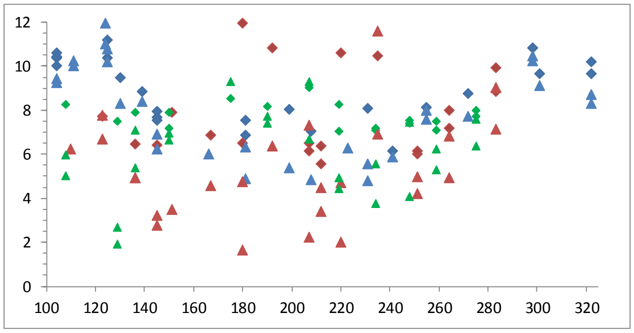
Dissolved oxygen saturation (DO%SAT) is a measure of the productivity potential in the water based on DO and temperature. Readings typically exceed 100% saturation when there are algal blooms, clear water, and favorable oxygen conditions. Our readings showed that DO%SAT readings exceeded 100% at most locations a couple of times during 2014 (Figures 13a-e). DO%SAT readings were lower as stations were located lower in the Cuyahoga River. LR2 and especially LR3 had many occasions where DO%SAT readings were 60% or below, exhibiting impaired (turbid, poor DO, stagnant) conditions.



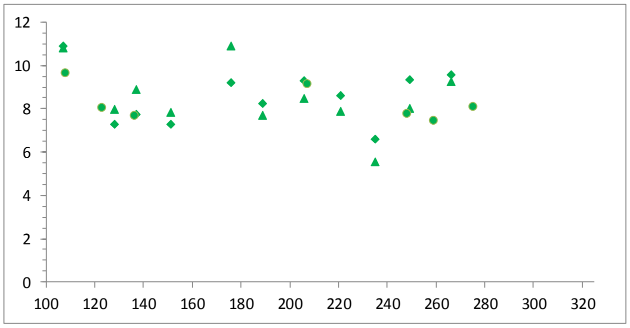
Surface DO in mg/l   Julian Day reference: 100= Apr 10   150= May 30
Blue=2011, Red=2012, Green=2013   200= Jul 19   250= Sep 7
Diamond=H1, Triangle=H2   300= Oct 27



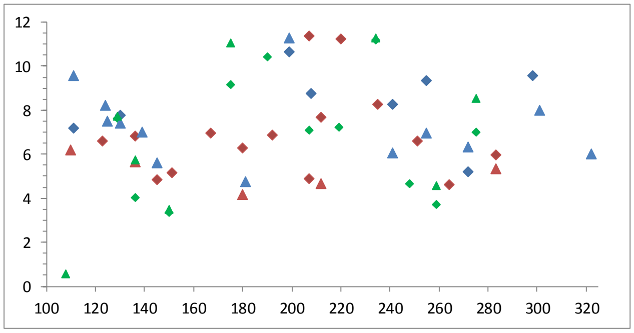
Surface DO in mg/l
Blue=2011, Red=2012, Green=2013
Diamond=OB1, Triangle=OB2



Surface DO in mg/l
Blue=2011, Red=2012, Green=2013
Diamond=LR1, Triangle=LR2

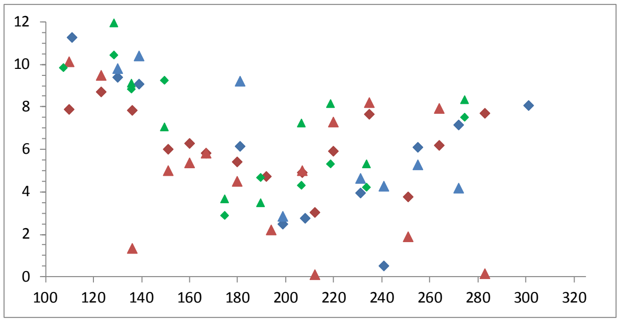


Surface DO in mg/l
Green=2013
Diamond=GR1, Triangle=GR2, Circle=LR0.

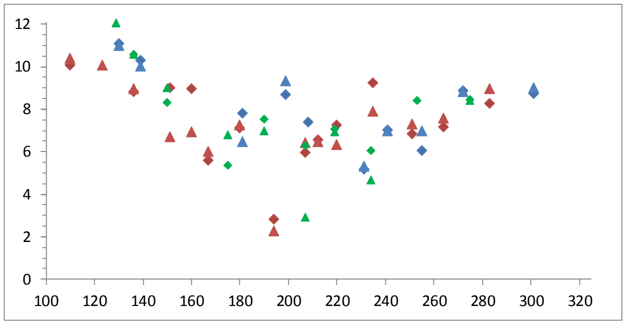


Surface DO in mg/l
Blue=2011, Red=2012, Green=2013
Diamond=OC1, Triangle=OC2

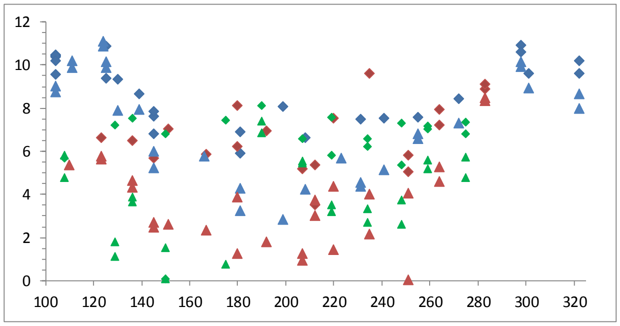
Figure 11a. Surface water dissolved oxygen readings at sampling stations in 2011-2013.



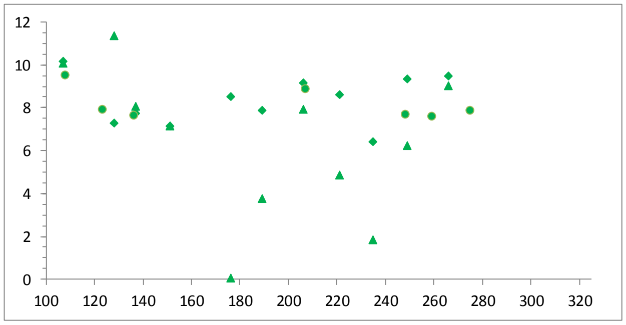
Bottom DO in mg/l Julian Day reference: 100= Apr 10 150= May 30
Blue=2011, Red=2012, Green=2013 200= Jul 19 250= Sep 7
Diamond=H1, Triangle=H2 300= Oct 27



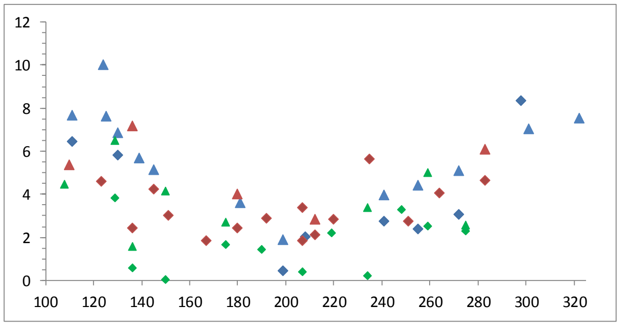
Bottom DO in mg/l
Blue=2011, Red=2012, Green=2013
Diamond=OB1, Triangle=OB2



Bottom DO in mg/l
Blue=2011, Red=2012, Green=2013
Diamond=LR1, Triangle=LR2



Bottom DO in mg/l
Green=2013
Diamond=GR1, Triangle=GR2, Circle=LR0.



Bottom DO in mg/l
Blue=2011, Red=2012, Green=2013
Diamond=OC1, Triangle=OC2

Figure 11b. Bottom water dissolved oxygen readings at sampling stations in 2011-2013.

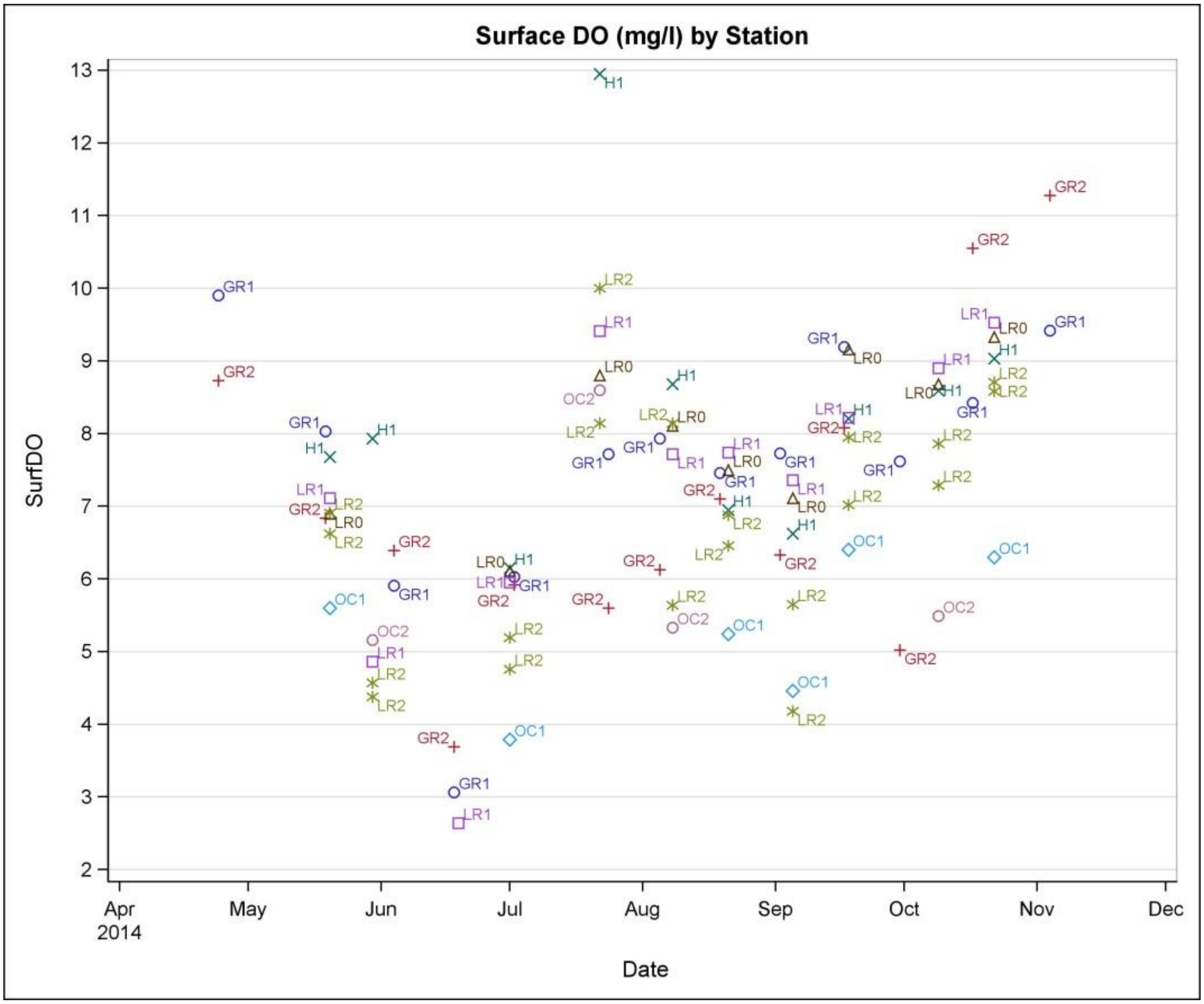


Figure 11c. Surface water dissolved oxygen readings at sampling stations in 2014.

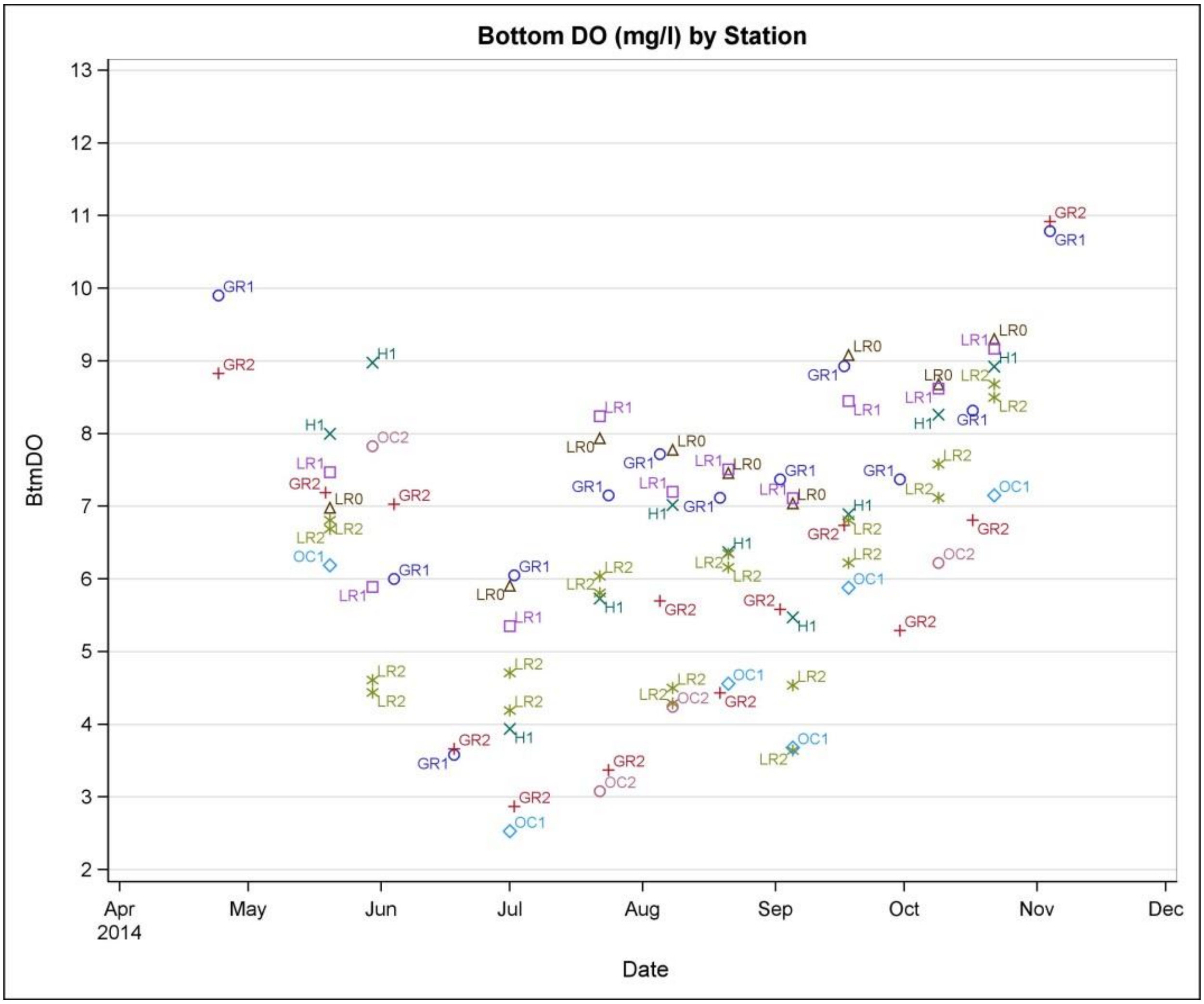


Figure 11d. Bottom water dissolved oxygen readings at sampling stations in 2014.

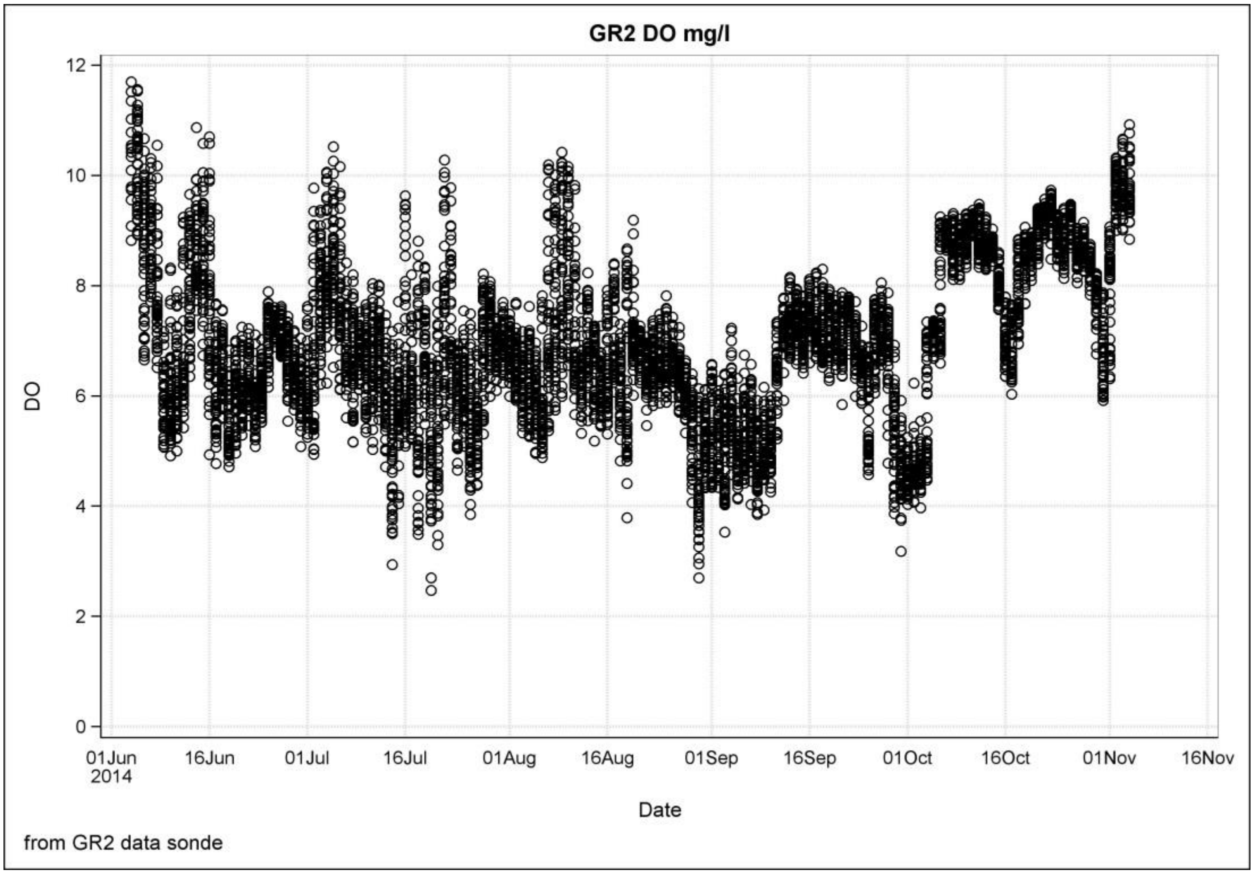


Figure 12a. Grand River Station GR2 (Grand R Marine) dissolved oxygen recorded from the data sonde.

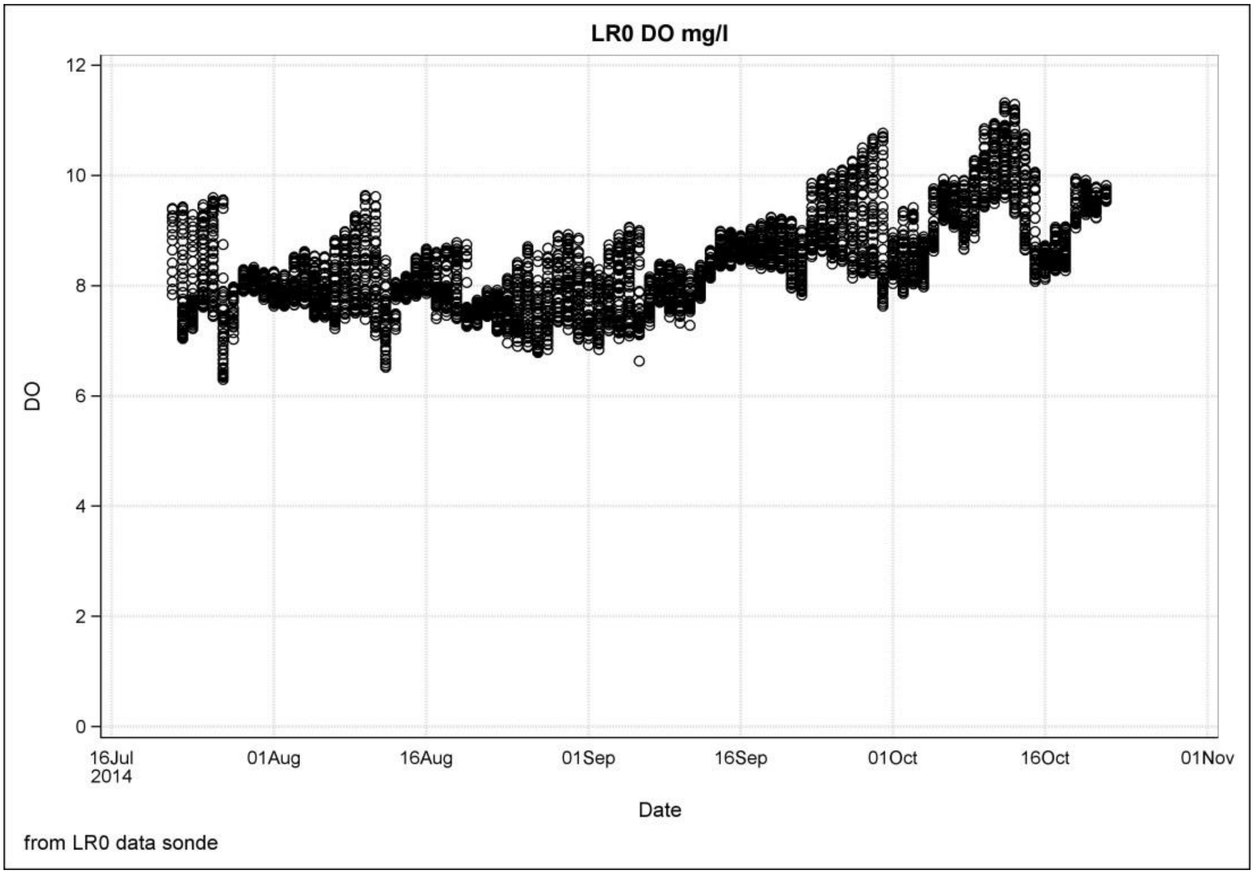


Figure 12b. Cuyahoga River Station LR0 (1st riffle) dissolved oxygen recorded from the data sonde.

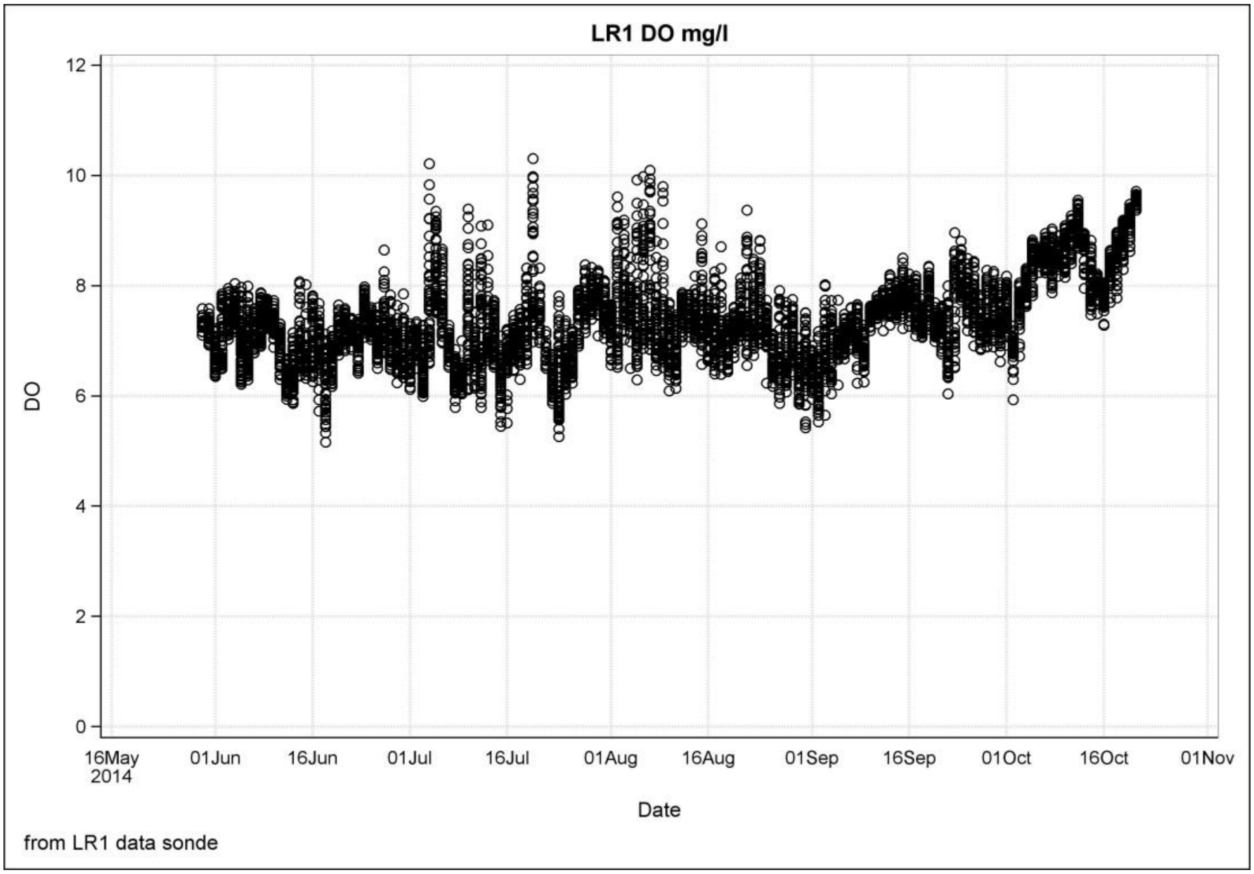


Figure 12c. Cuyahoga River Station LR1 (I-490) dissolved oxygen recorded from the data sonde.

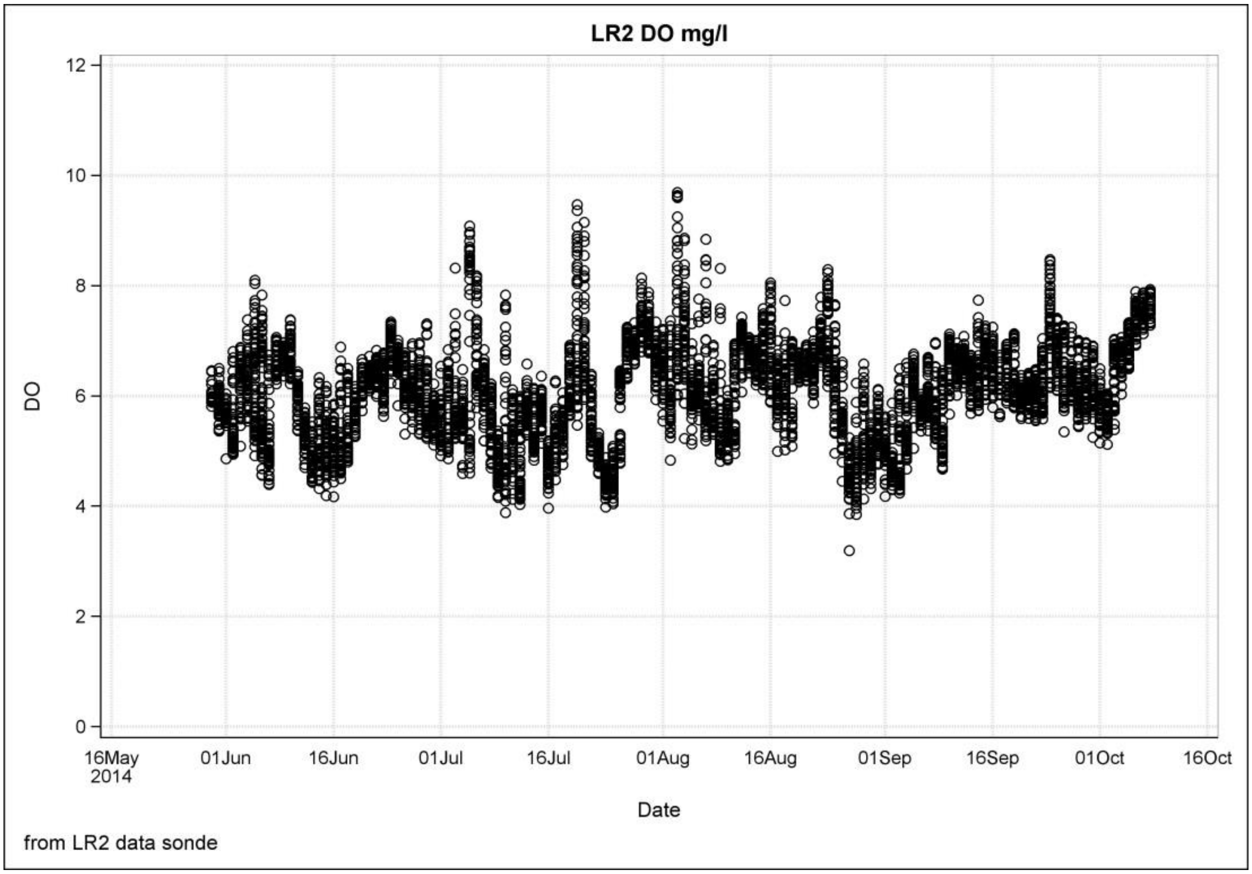


Figure 12d. Cuyahoga River Station LR2 (I-90) dissolved oxygen recorded from the data sonde.

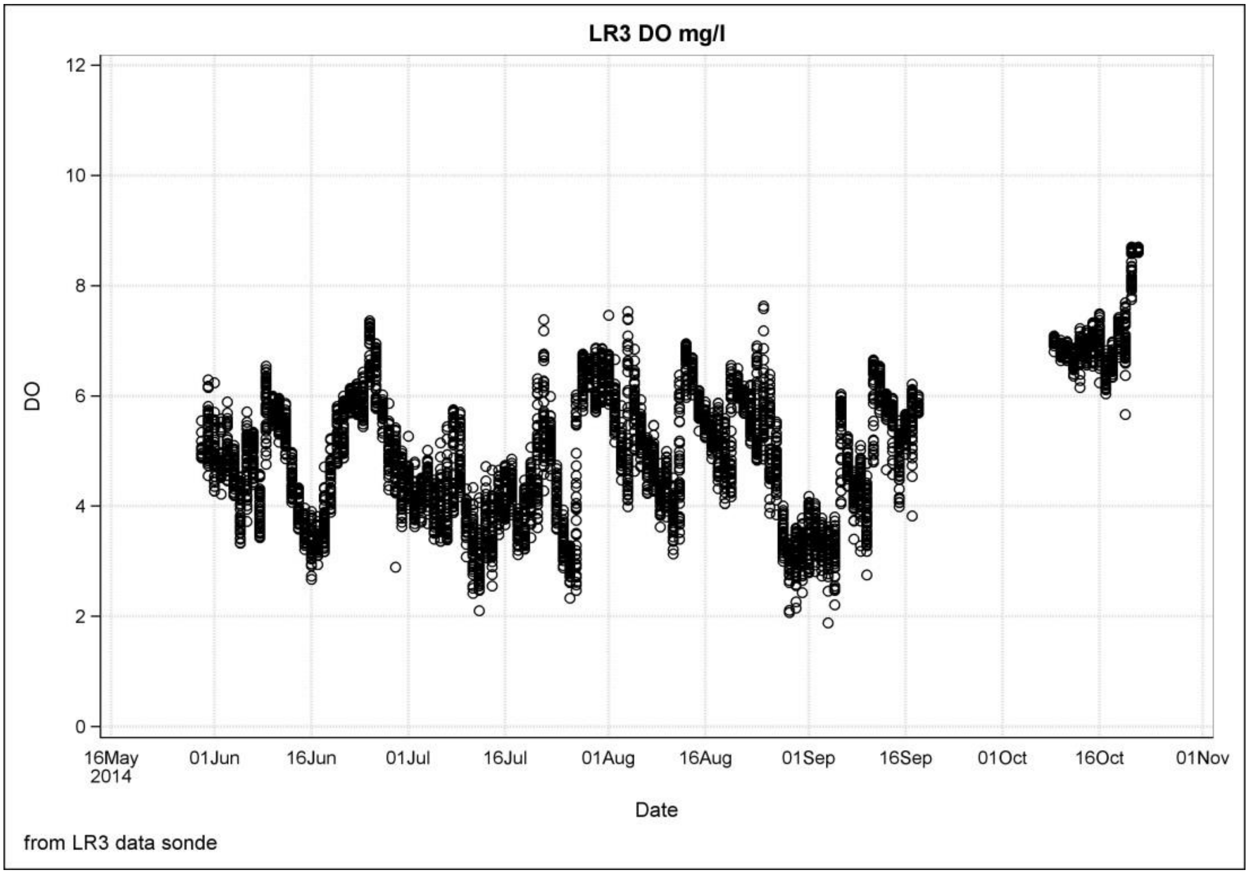


Figure 12e. Cuyahoga River Station LR3 (Samsel's) dissolved oxygen recorded from the data sonde.

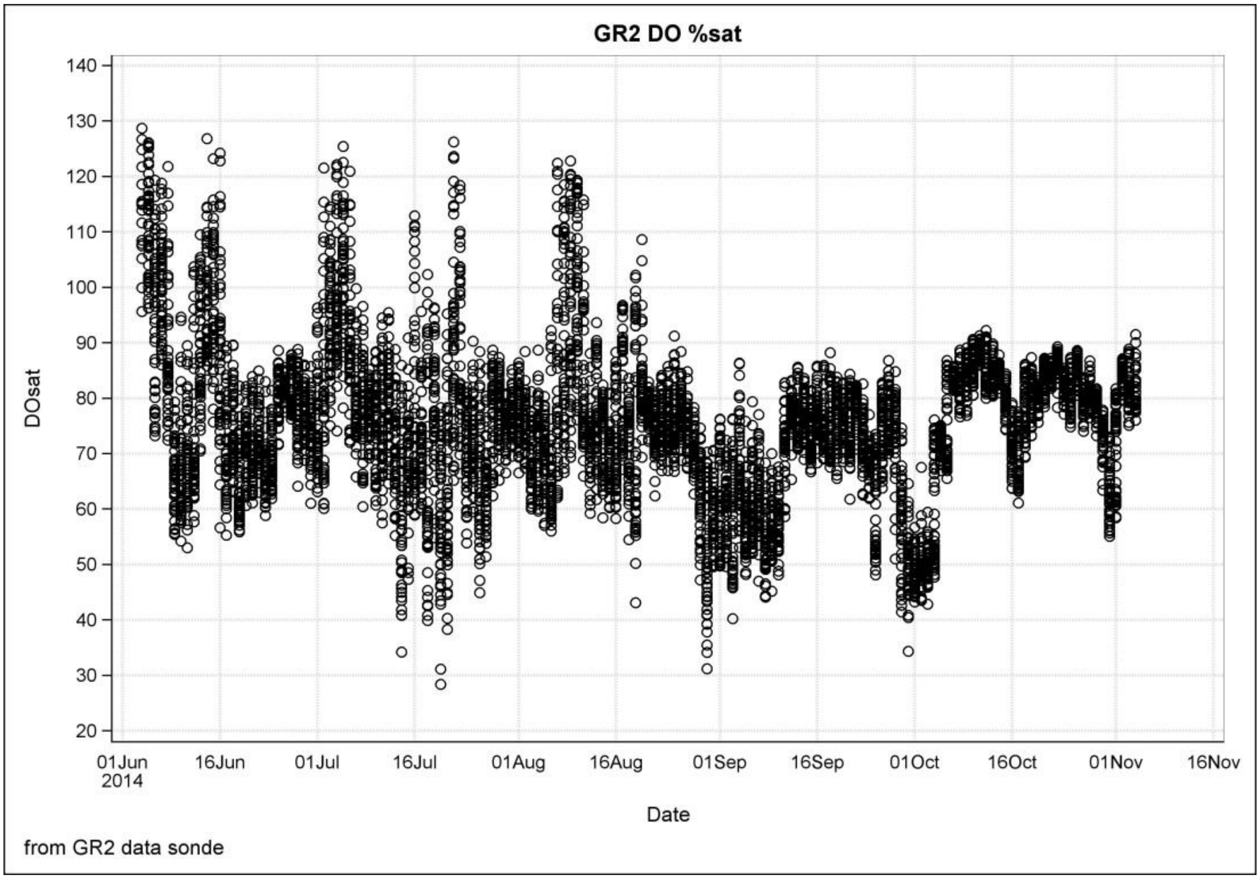


Figure 13a. Grand River Station GR2 (Grand R Marine) DO % saturation recorded from the data sonde.

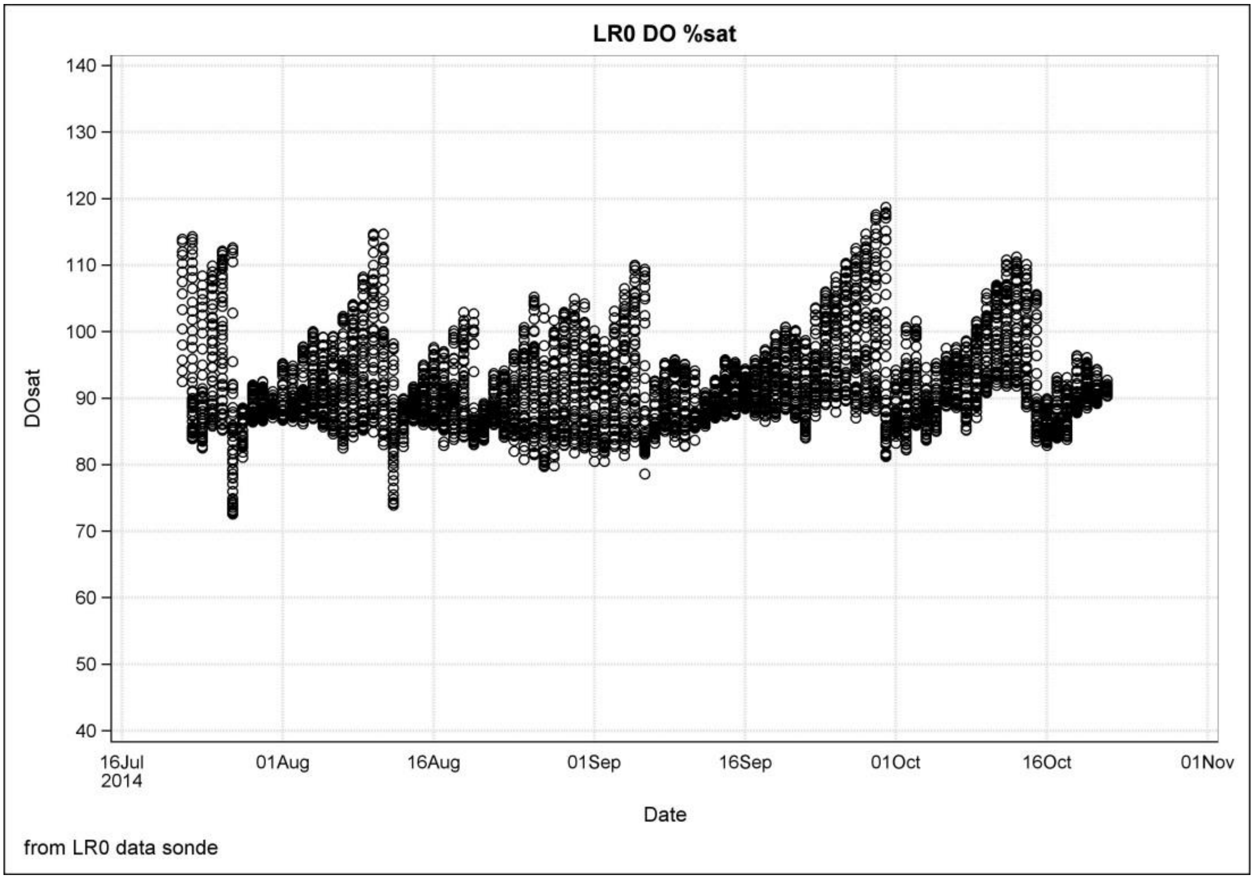


Figure 13b. Cuyahoga River Station LR0 (1st riffle) DO % saturation recorded from the data sonde.

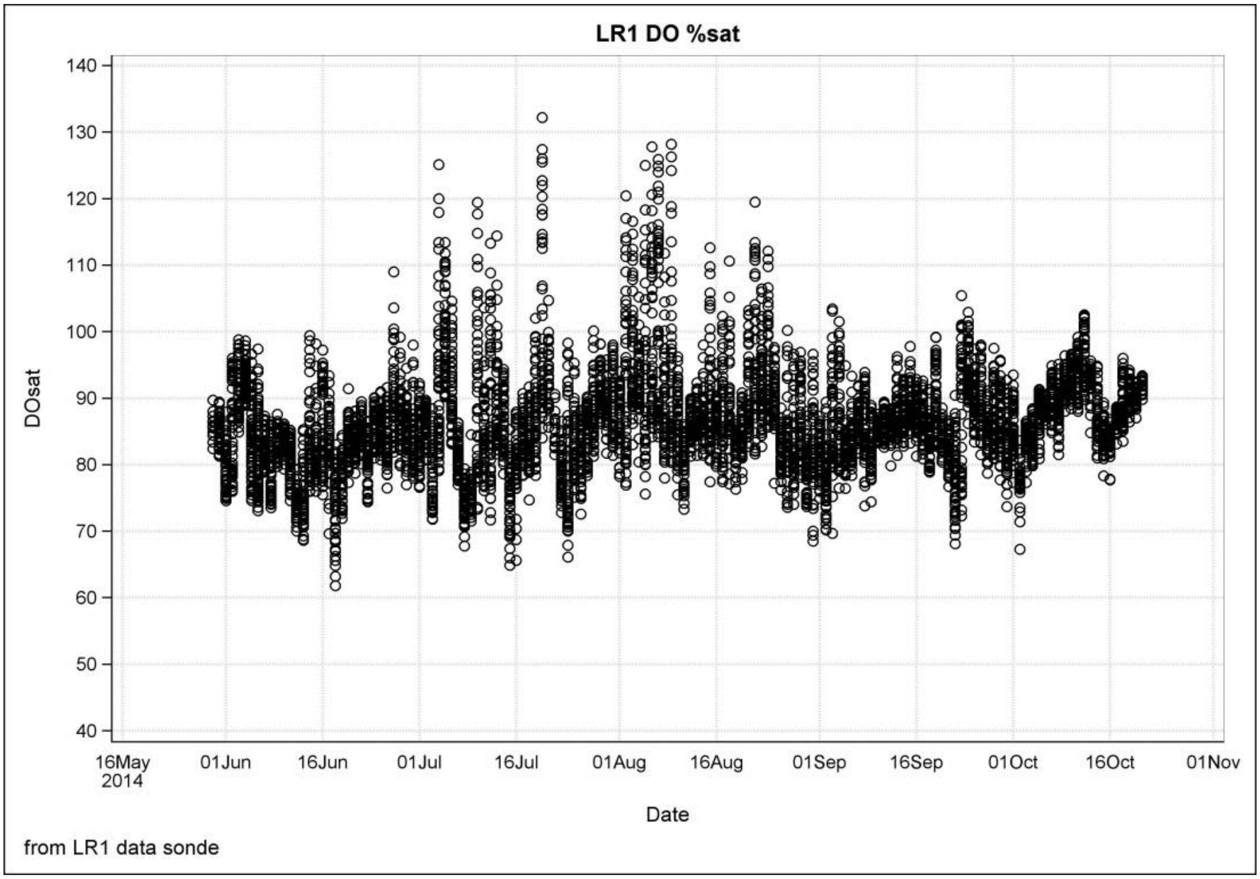


Figure 13c. Cuyahoga River Station LR1 (I-490) DO % saturation recorded from the data sonde.

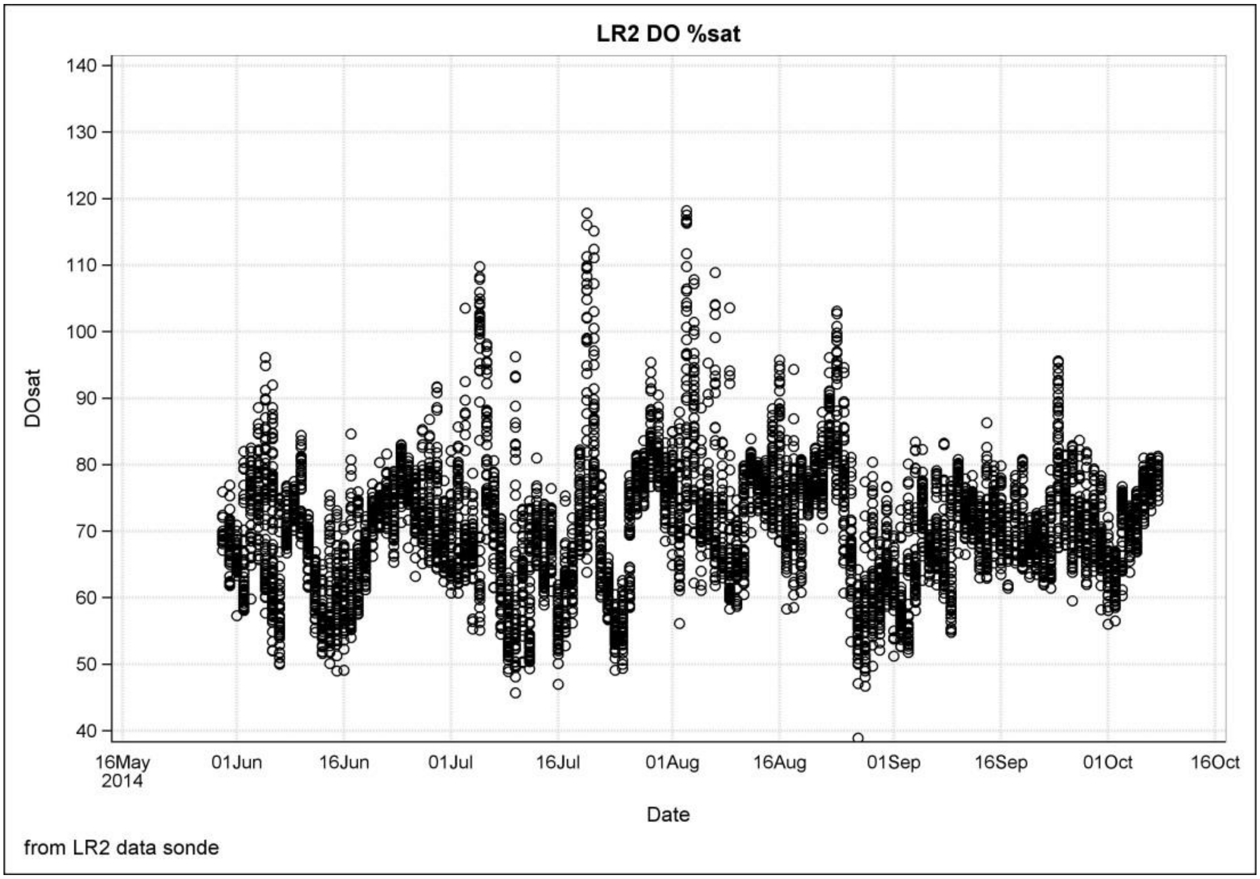


Figure 13d. Cuyahoga River Station LR2 (I-90) DO % saturation recorded from the data sonde.

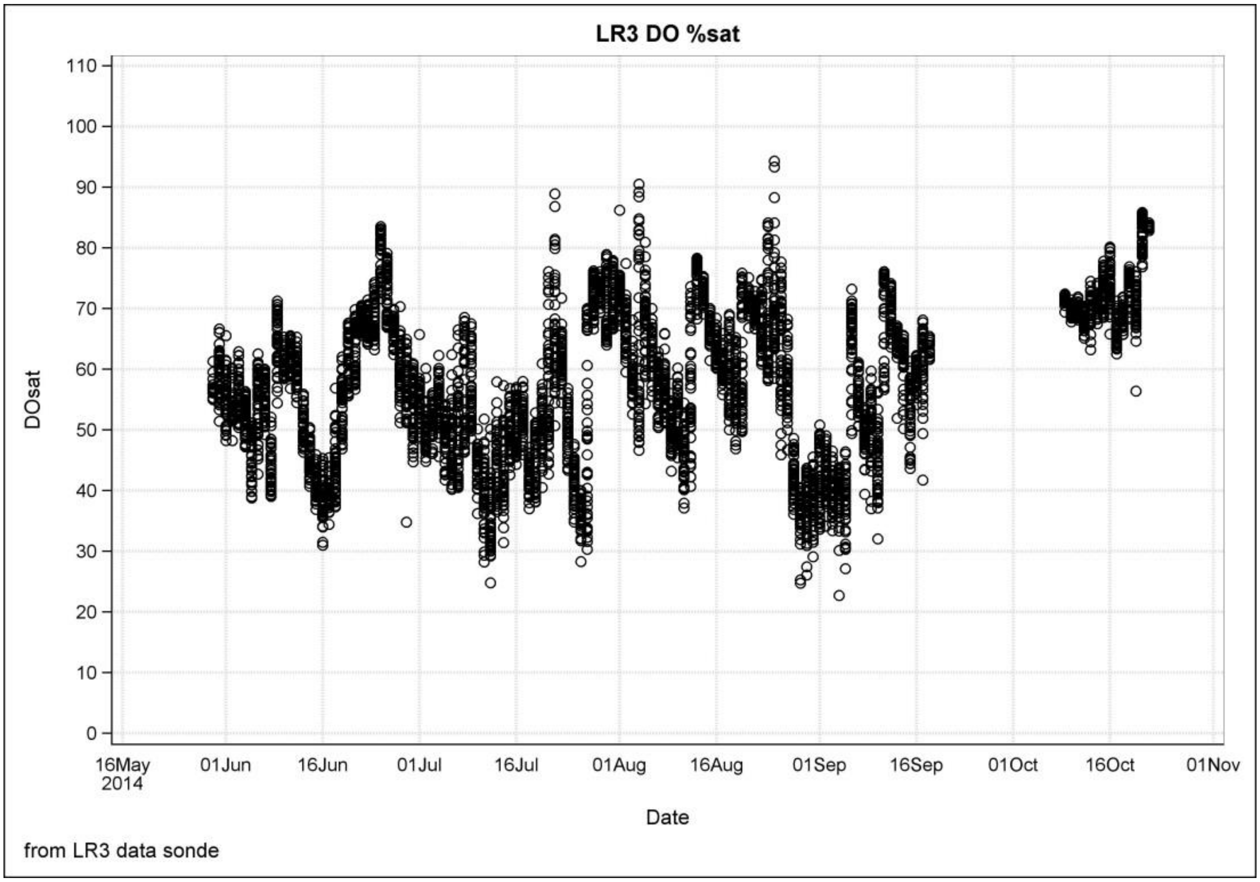


Figure 13e. Cuyahoga River Station LR3 (Samsel's) DO % saturation recorded from the data sonde.

Secchi Disk readings and Light transmission

The Cuyahoga and Grand rivers are highly turbid river systems. We used a Secchi disk and a LiCor light meter to evaluate water clarity and transmission of light through the water column. Most of our Secchi disk readings were less than 1.0 meter (Figure 14). Rarely did we find ship channel Secchi readings greater than 0.5m. The frequency of large ship traffic and dredging operations further exacerbate this transparency problem. Upper Cuyahoga River (LR0), Cleveland Harbor (H1), and Grand River (GR) stations tended to have the best water clarity.

In Li-Cor light transmission readings through the water column, most of the available light was filtered out at a depth of 2-3 meters (Figure 15) from the surface. In non-riverine areas where samples were taken, outside Cleveland harbor and breakwall, similar light transmission levels were not observed until a depth of 5-6 meters (Figure 16). Only 10% (or less) of the available light was available at 1m at LR2 (Figure16). These light levels and water clarity are important indicators of the photic zone- where photosynthesis and plant growth activity can occur. There is a narrow area that light can penetrate in the water column to promote vegetative growth. This impairs the ability of the river and harbor to sequester energy and move it up through the food web. Compounded by the lack of current, abundant suspended sediments, and intermittent mixing of the water column through episodes from ship or storm inflow, the ship channel acts like very muddy, stagnant reservoir that slowly moves sediment and nutrients out to the harbor and lake. Only large water events in the regional watershed force the system to move or drain significant water masses into the harbor and lake.

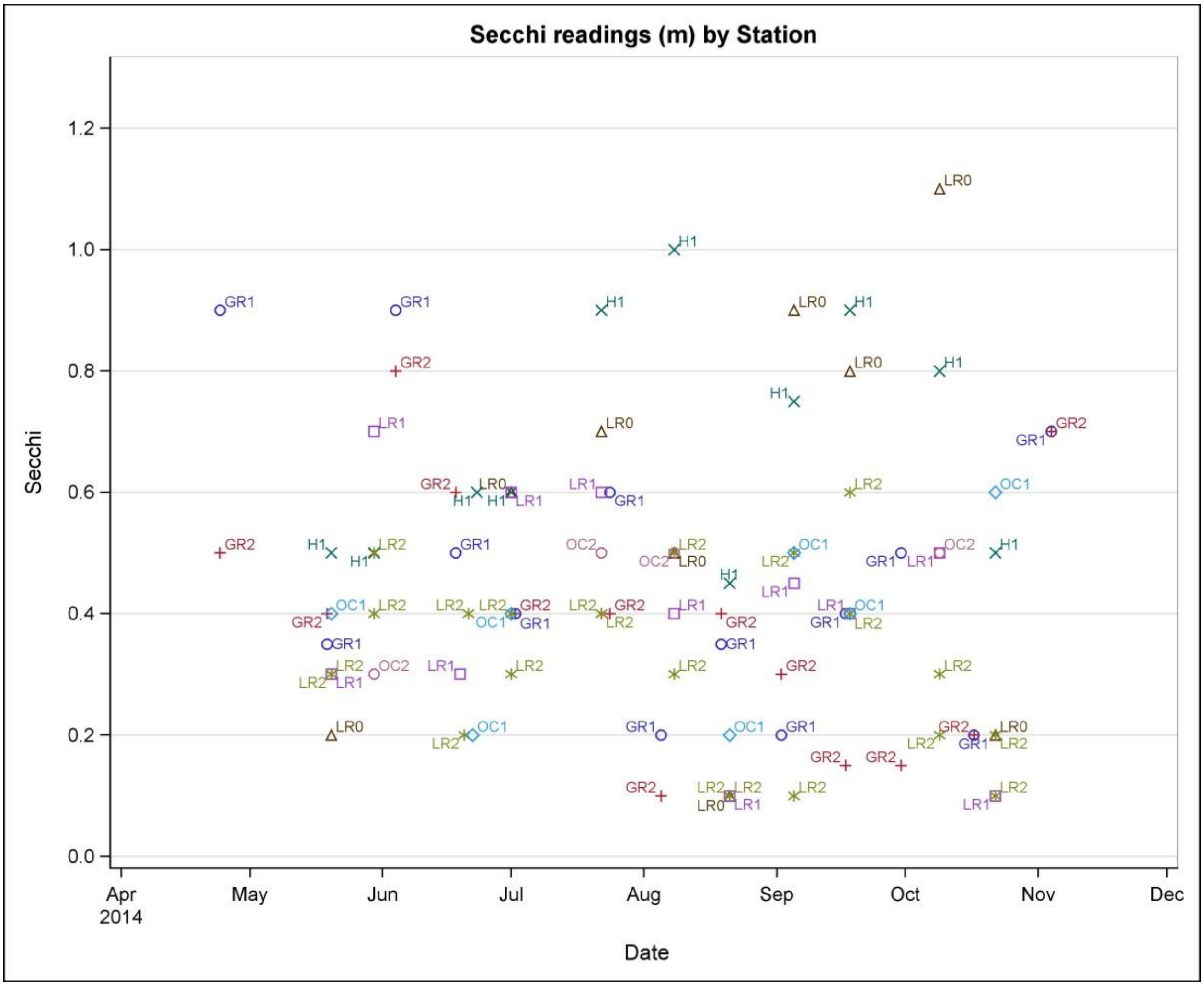


Figure 14. Secchi disk readings of water clarity at sample stations, 2014.

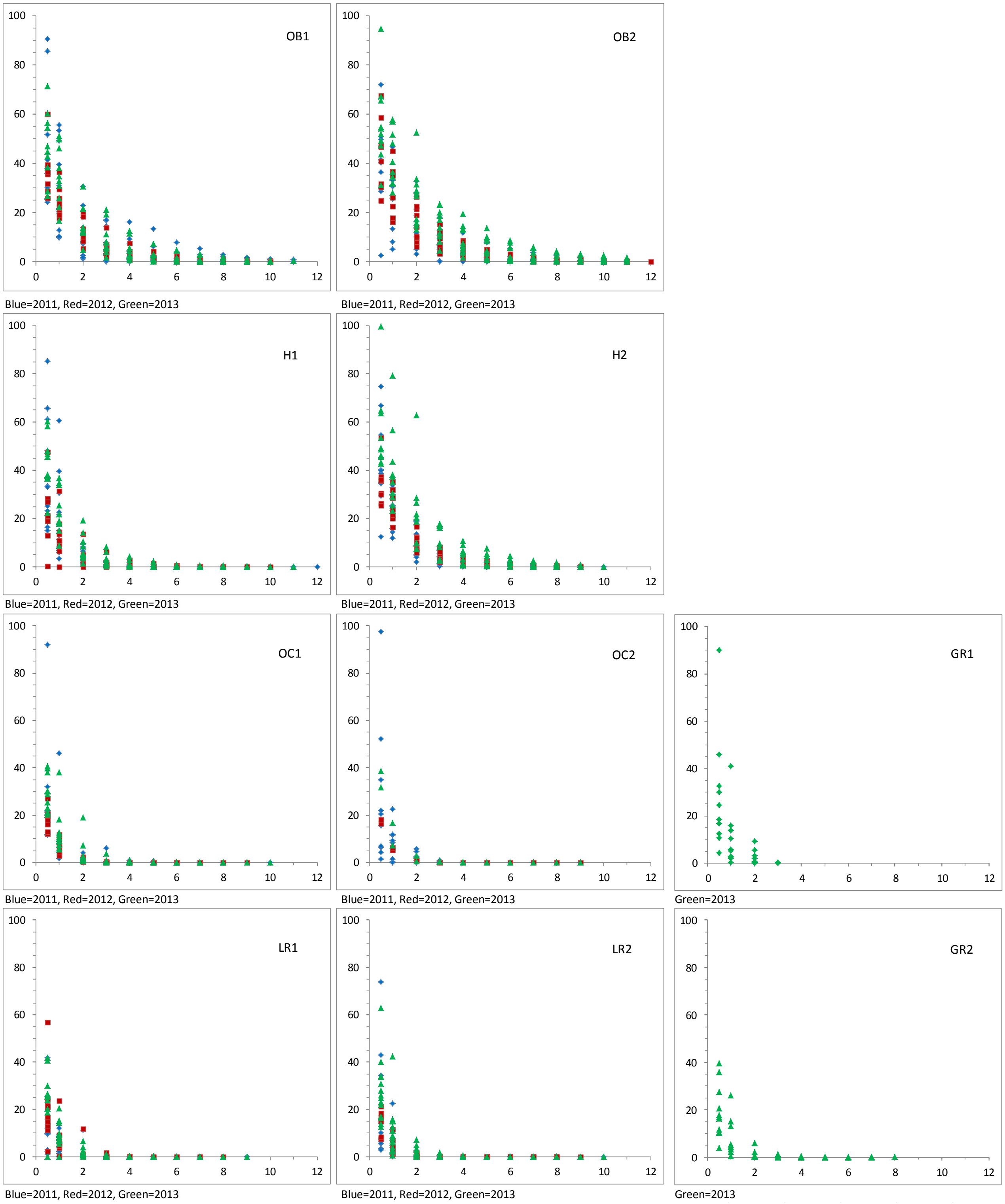
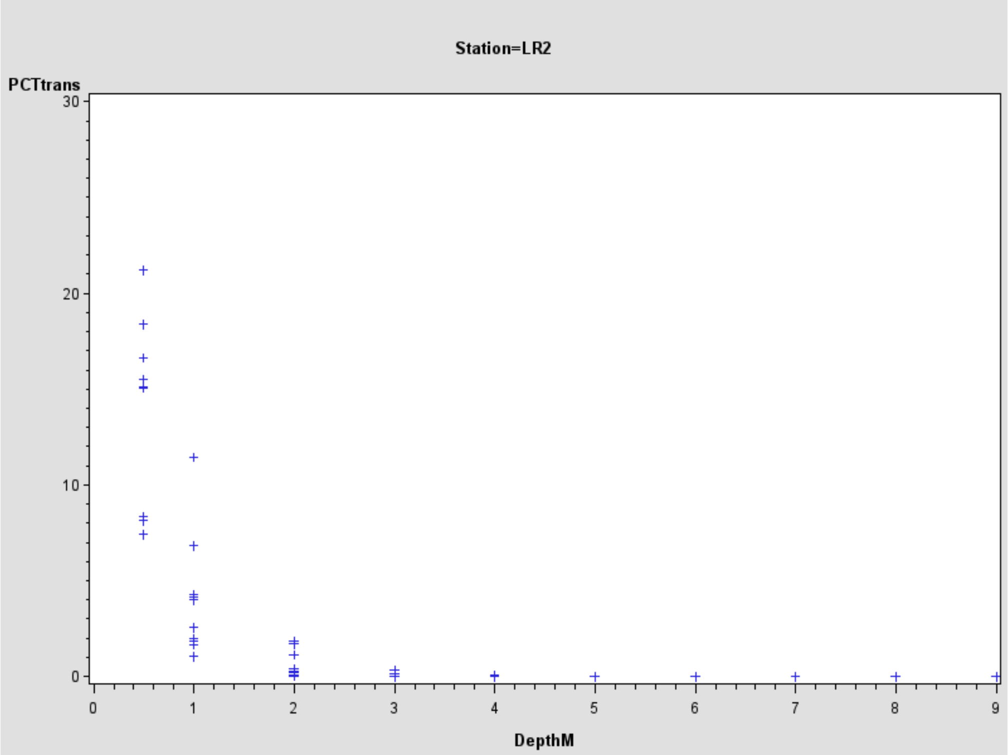


Figure 15. Li-Cor light transmission readings by year and location, expressed as a percentage of light transmitted through the water column to that depth, with values on the y-axes being that fraction recorded from light measured on the deck of the boat at that location and sampling time and x-axis values being the corresponding depth of the reading.



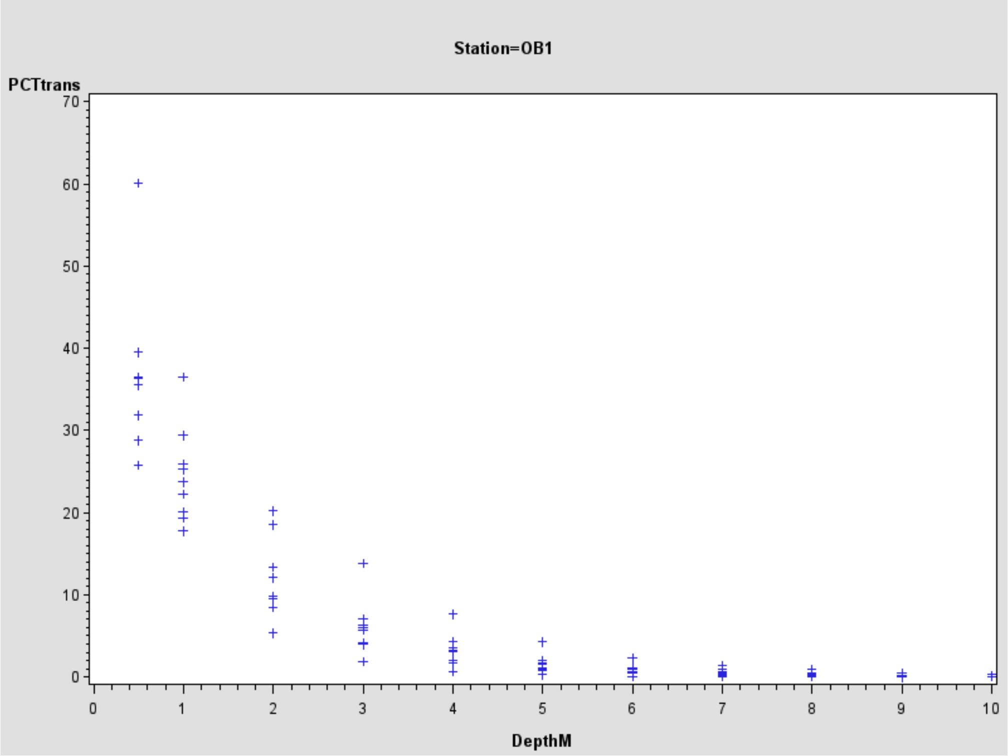


Figure 16. LiCor light meter readings of % light transmission at LR2 (top) and at a comparison station OB1 just outside of the Cleveland breakwall (bottom) for 2014.

Total and Soluble Reactive Phosphorus (TP and SRP); Heidelberg University contract reports.

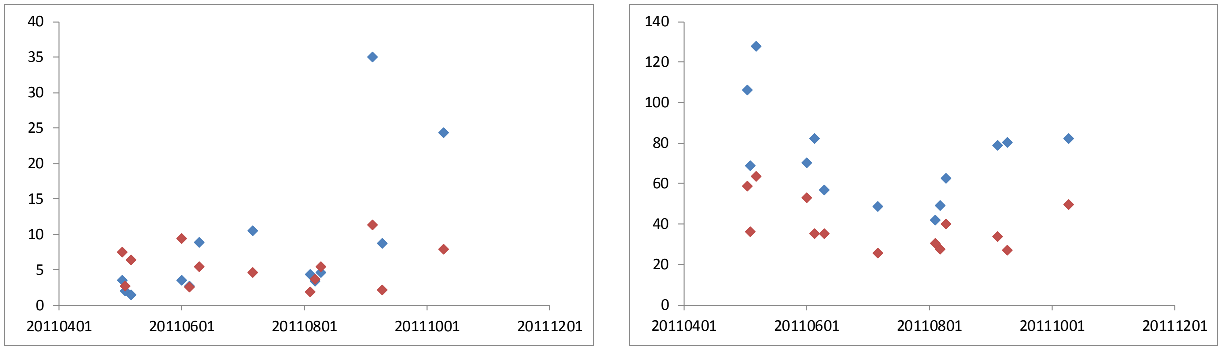
The abundance of phosphorus, measured as either total phosphorus (TP) or as soluble reactive phosphorus (SRP), is an indicator of trophic status. These measures serve to determine the amount of nutrients available for lower trophic life such as green algae and blue green algae. High concentrations of TP and SRP can lead to nutrient pulses resulting in harmful algal blooms and anoxic conditions in the central basin of Lake Erie (or potentially in the ship channel if nutrients and algae are not moved out of the system). We collected water samples at our stations in 2011-2014 in order to determine nutrient levels for comparison to other systems and known targets/standards as set in the Great Lakes Water Quality Agreement and in the Great Lakes Fishery Commission, Lake Erie Committee's Fish Community Goals and Objectives (Ryan et al. 2003). Samples were analyzed and reported out by the Heidelberg University's National Center for Water Quality Research (NCWQR).

From the data we collected, we see a pattern of increased P loading during the spring through the summer, then declining into the fall (Figures 17 a-d). For nearly all sample dates, the Grand River sites were lower than the Cuyahoga River sites. There were a few exceptions early in the spring of 2014. All of the values push P levels into eutrophic or hyper-eutrophic conditions (those TP levels exceeding 50-100 ug/l). When comparing the Cuyahoga River mean daily TP reading to those of the Maumee and Sandusky rivers, the Cuyahoga River is less of a nutrient source to Lake Erie: mean daily TP from Jan 1, 2013 to July 1, 2014 (latest date for available data in all 3 systems) was 0.173 mg/l (or 173 ug/l) for the Cuyahoga, 0.265 mg/l for the Sandusky, and 0.240 mg/l for the Maumee. These values show that while nutrients are coming out of the Cuyahoga River and into the central basin of Lake Erie, the levels are not at exceedingly high levels compared to other adjacent streams and watersheds that also are major sources of nutrients that fuel harmful algal blooms in Lake Erie.

Other data sonde/Heidelberg NCWQR data

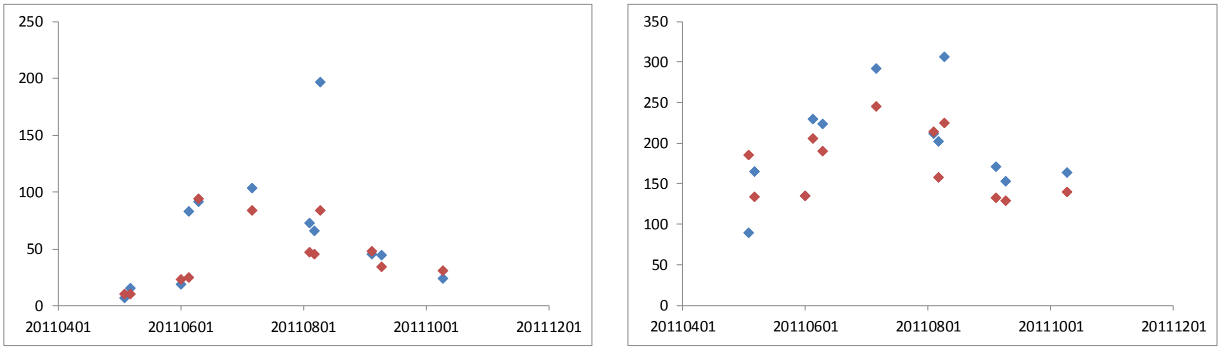
Other data collected in our data sondes includes turbidity, pH, conductivity, total dissolved solids, specific conductance, salinity, and measures of chlorophyll and blue green algae activity. Tables 6a and 6b show statistical results for these parameters by data sonde location. The mean and variation observed for these variables did not indicate major impairments (with the exception of high turbidity readings throughout the four-year study period. There were small significant differences between the Cuyahoga and Grand for dissolved solids, conductivity and specific conductance; however, some missing data from the Grand data sonde complicates that comparison. Both data sets show typical variation from rivers with agricultural, suburban and urban mixed use watersheds. Figures for the data sonde continuous data gathered in 2014 are presented in Appendix 2.

Additional data collected at sample stations and reported by the NCWQR at Heidelberg University include measures of water quality such as total suspended solids, nitrate/nitrite, Kjeldahl N, chloride, sulfate, silica, and conductivity. These data are also included as part of the complete project dataset and are available online from the NCWQR of Heidelberg University at: http://www.heidelberg.edu/academiclife/distinctive/ncwqr/data .



SRP blue=H1
red= H2

TP blue=H1
red= H2



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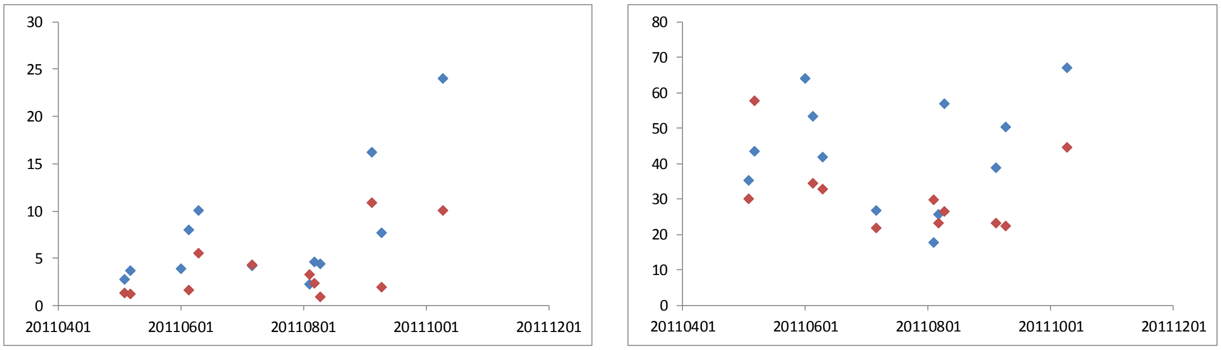
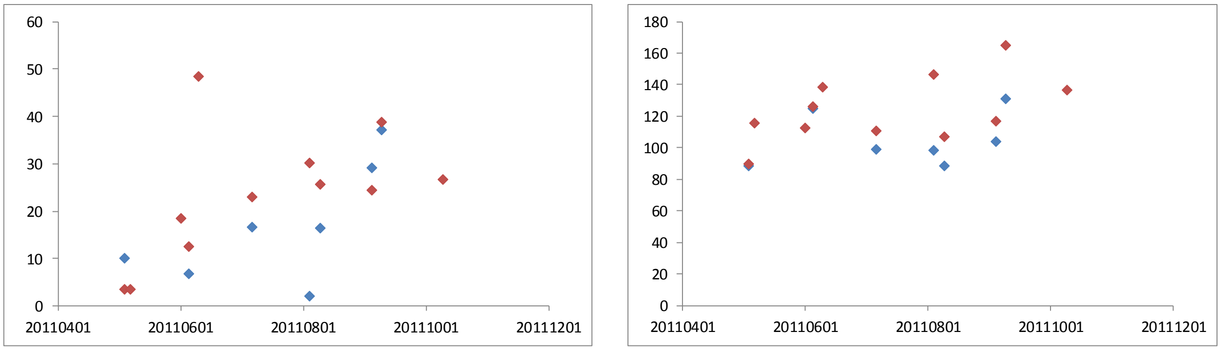


SRP blue=OB1
red= OB2

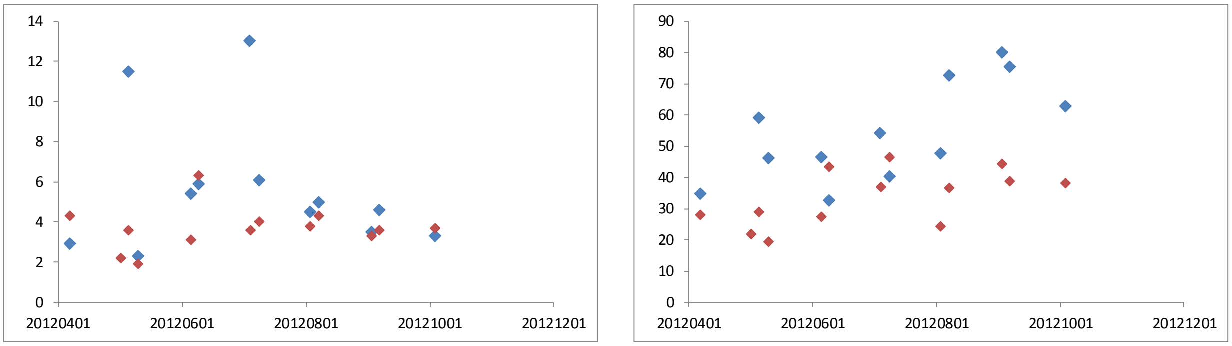
TP blue=OB1
red= OB2



SRP blue=OC1
red= OC2

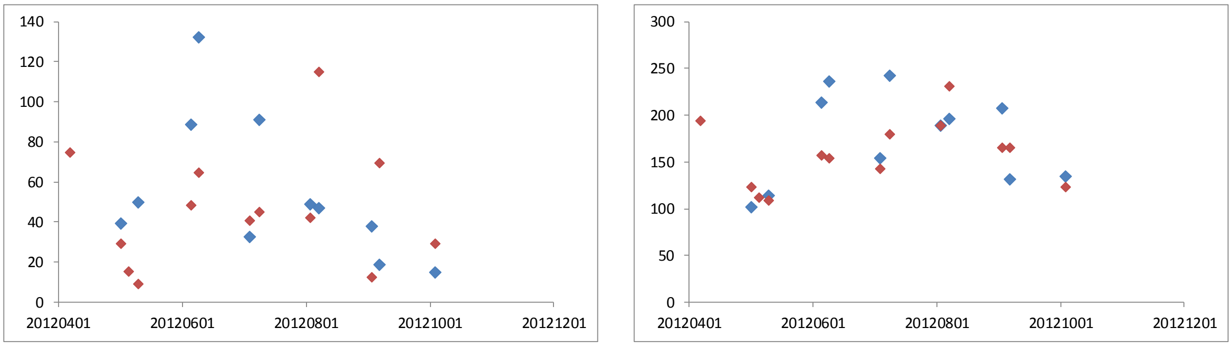
TP blue=OC1
red= OC2

Figure 17a. Results of Soluble Reactive Phosphorus (SRP) and Total Phosphorus (TP) for samples taken in 2011 in the Cuyahoga R AOC sampling locations. Y-axis values are ug/l.



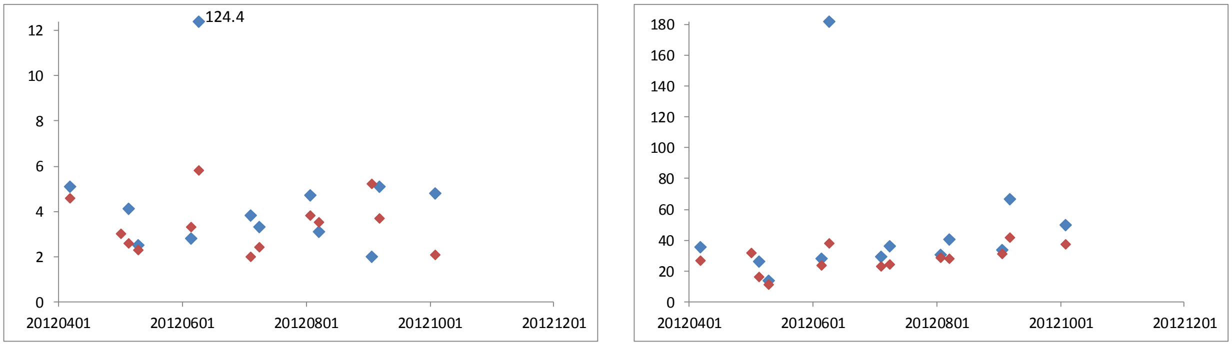
SRP blue=H1
red= H2

TP blue=H1
red= H2



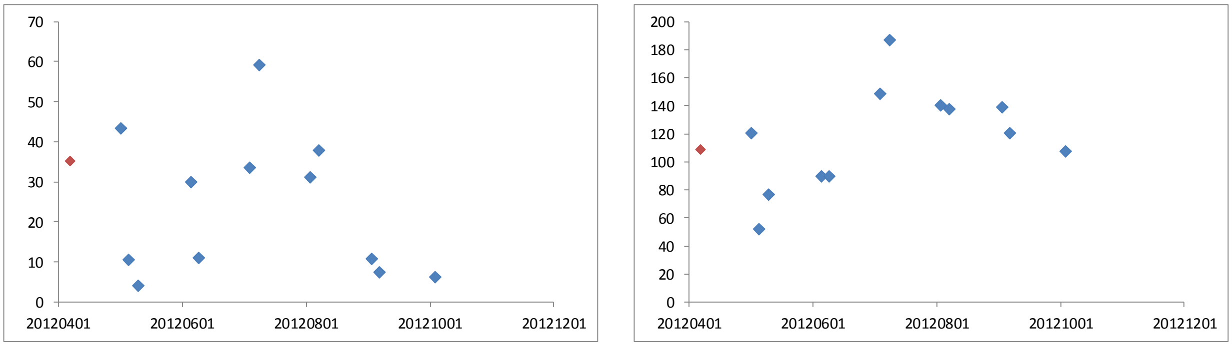
SRP blue=LR1
red= LR2

TP blue=LR1
red= LR2



SRP blue=OB1
red= OB2

TP blue=OB1
red= OB2



SRP blue=OC1
red= OC2

TP blue=OC1
red= OC2

Figure 17b. Results of Soluble Reactive Phosphorus (SRP) and Total Phosphorus (TP) for samples taken in 2012 in the Cuyahoga R AOC sampling locations. Y-axis values are ug/l.

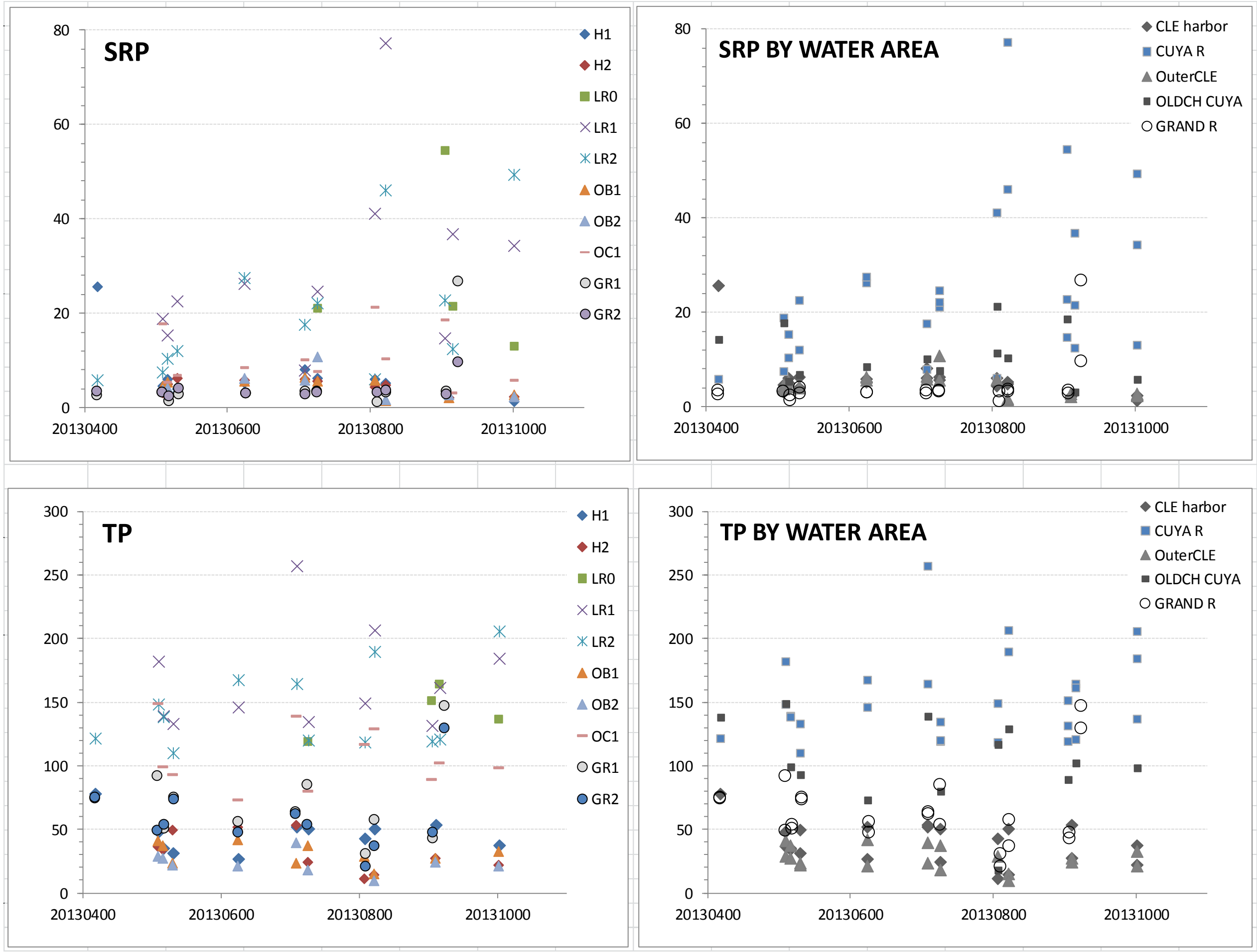


Figure 17c. Results of Soluble Reactive Phosphorus (SRP) and Total Phosphorus (TP) for samples taken in 2013 in the Cuyahoga River AOC and Grand River sampling locations. Y-axis values are ug/l.

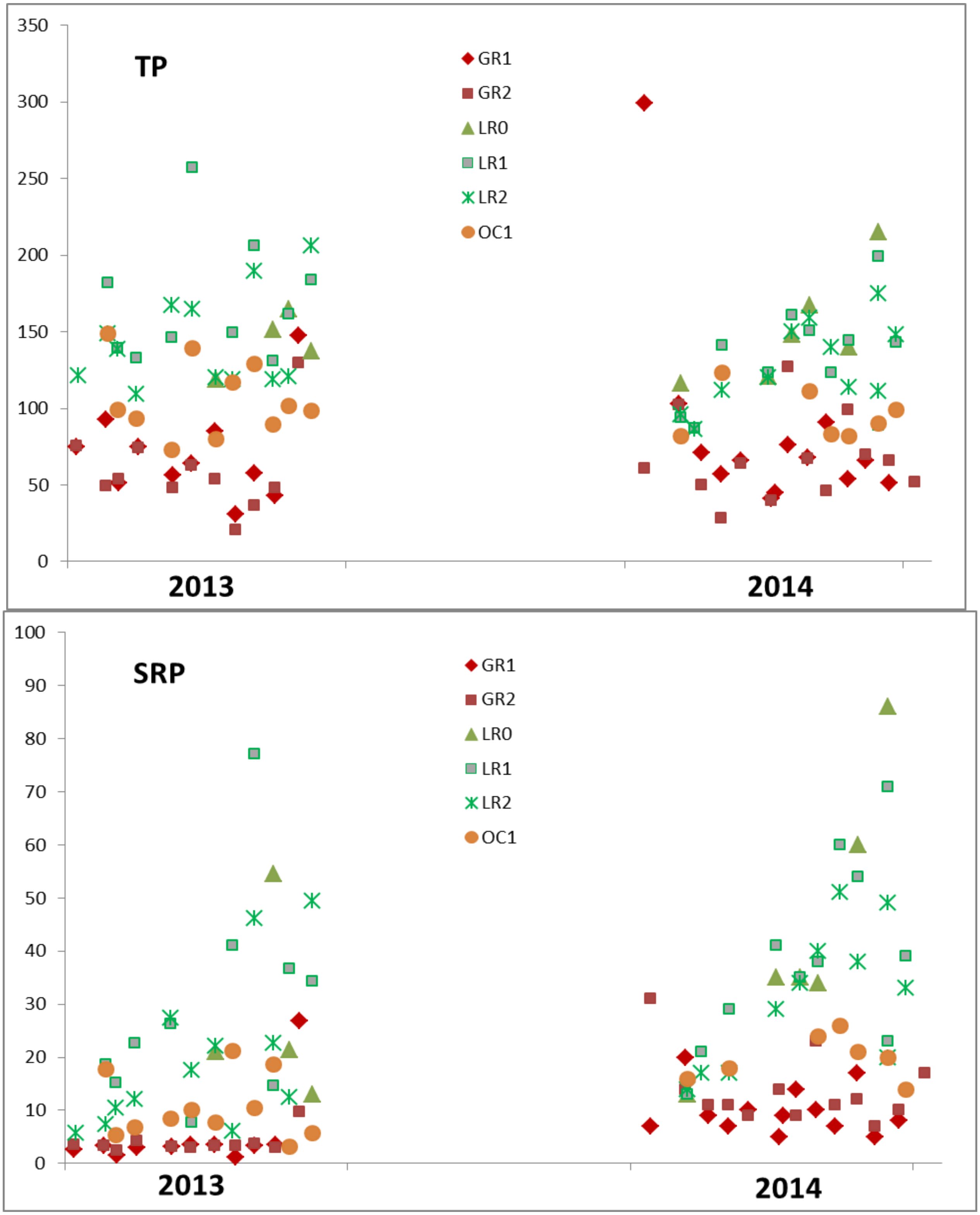


Figure 17d. Soluble reactive phosphorus (SRP, top) and total phosphorus (TP) measured at Cuyahoga and Grand River sampling stations from April-early November 2013 and 2014. Y-axis values are ug/l.

Table 6a. Data sonde summaries for Cuyahoga River sites.

Data Sonde summaries 2014		Edited data, transitions excluded		Cuyahoga River sites

LR0	7/22/2014-10/22/2014

Variable	N	Mean	Std Dev	Min	Max	1st Pctl	5th Pctl	10th Pctl	25th Pctl	50th Pctl	75th Pctl	90th Pctl	95th Pctl	99th Pctl
Temp	4417	19.767	3.162	12.609	25.110	13.0	13.8	14.5	17.6	20.5	22.3	23.4	23.8	24.6
DOsat	4417	91.761	6.679	72.60	118.70	80.5	83.8	85.1	87.2	90.2	94.8	101.4	105.6	112
DO	4417	8.397	0.844	6.30	11.32	6.88	7.25	7.44	7.77	8.27	8.89	9.64	9.93	10.74
Turbidity	4417	47.669	127.051	2.1	2211.4	3.4	4.1	4.7	7.2	13.2	28.5	93.2	212	668.6
pH	4417	7.983	0.129	7.58	8.39	7.65	7.73	7.82	7.91	7.99	8.06	8.13	8.19	8.28
Cond	4417	690	124	332	1102	424	494	528	610	688	761	831	908	1024
TDS	4417	449	80	216	716	276	321	343	397	447	495	540	590	666
SpCond	4417	770	139	362	1139	456	534	580	674	778	851	984	1029	1083
Sal	4417	0.378	0.071	0.17	0.57	0.22	0.26	0.28	0.33	0.38	0.42	0.49	0.51	0.54
Chl_RFU	4417	0.774	0.519	-0.01	4.82	0.06	0.17	0.22	0.39	0.69	0.98	1.47	1.78	2.55
Chl_ugL	4417	2.974	1.783	0.30	16.87	0.51	0.89	1.08	1.66	2.70	3.67	5.37	6.44	9.08
BGA_RFU	4417	0.182	0.233	-0.09	1.22	-0.07	-0.05	-0.04	0.00	0.11	0.30	0.51	0.68	0.93
BGA_ugL	4417	0.182	0.233	-0.09	1.22	-0.07	-0.05	-0.04	0.00	0.11	0.30	0.51	0.68	0.93

LR1	5/30/2014-10/22/2014

Variable	N	Mean	Std Dev	Min	Max	1st Pctl	5th Pctl	10th Pctl	25th Pctl	50th Pctl	75th Pctl	90th Pctl	95th Pctl	99th Pctl
Temp	6899	23.347	2.945	13.199	30.125	15.7	17.4	18.6	21.9	23.8	25.6	26.7	27.2	27.9
DOsat	6899	86.319	7.354	61.80	132.20	71.4	75.5	78.1	81.9	85.6	90	94.7	98.4	112.3
DO	6899	7.359	0.735	5.16	10.31	5.88	6.3	6.5	6.86	7.28	7.74	8.44	8.78	9.38
Turbidity	6899	45.875	105.825	4.5	5519.1	7.0	10.2	12.6	17	24.9	38.2	78.6	159.4	415.9
pH	6899	7.857	0.112	7.50	8.35	7.59	7.67	7.72	7.78	7.86	7.93	7.99	8.04	8.16
Cond	6899	801	153	359	1137	453	536	591	686	818	898	1008	1055	1105
TDS	6899	521	99	233	739	294	348	384	446	531	584	655	686	718
SpCond	6899	827	147	389	1115	479	565	622	722	836	943	1016	1049	1084
Sal	6899	0.405	0.075	0.19	0.55	0.23	0.27	0.3	0.35	0.41	0.46	0.5	0.52	0.53
Chl_RFU	6899	1.144	0.829	0.14	12.22	0.22	0.32	0.42	0.65	0.89	1.37	2.22	2.79	4.34
Chl_ugL	6899	4.180	2.937	0.63	43.45	0.91	1.25	1.63	2.44	3.27	4.97	8.00	10.02	15.52
BGA_RFU	6899	0.393	0.287	0.05	1.84	0.09	0.11	0.13	0.18	0.30	0.52	0.78	1.00	1.39
BGA_ugL	6899	0.393	0.287	0.05	1.84	0.09	0.11	0.13	0.18	0.30	0.52	0.78	1.00	1.39

LR2	5/30/2014-10/8/2014

Variable	N	Mean	Std Dev	Min	Max	1st Pctl	5th Pctl	10th Pctl	25th Pctl	50th Pctl	75th Pctl	90th Pctl	95th Pctl	99th Pctl
Temp	6287	22.950	2.213	16.252	27.321	16.5	19.3	20.0	21.6	23.2	24.7	25.6	25.9	26.5
DOsat	6287	70.685	9.375	38.90	118.20	51.8	55.7	58.8	64.6	70.6	76.2	80.8	85.1	100.5
DO	6287	6.069	0.855	3.19	9.69	4.31	4.65	4.93	5.46	6.09	6.64	7.1	7.41	8.3
Turbidity	6287	38.052	56.458	4.0	1661.7	6.2	9.1	10.9	15.3	21.8	34	73.9	133.5	298.6
pH	6287	7.734	0.107	7.44	8.38	7.49	7.58	7.61	7.67	7.73	7.79	7.85	7.91	8.11
Cond	6287	770	163	376	1317	433	507	548	649	769	897	990	1049	1082
TDS	6287	501	106	244	856	281	330	356	422	500	583	643	682	704
SpCond	6287	801	161	407	1289	459	528	572	676	816	919	1012	1066	1101
Sal	6287	0.392	0.082	0.20	0.64	0.22	0.25	0.28	0.33	0.4	0.45	0.5	0.53	0.55
Chl_RFU	6287	1.250	0.821	0.24	13.21	0.33	0.44	0.53	0.76	1.01	1.47	2.2	2.86	4.23
Chl_ugL	6287	5.018	3.193	1.11	51.49	1.45	1.88	2.24	3.13	4.07	5.88	8.73	11.29	16.59
BGA_RFU	6287	0.188	0.253	-0.08	1.72	-0.05	-0.03	-0.02	0.01	0.09	0.29	0.52	0.73	1.14
BGA_ugL	6287	0.188	0.253	-0.08	1.72	-0.05	-0.03	-0.02	0.01	0.09	0.29	0.52	0.73	1.14

LR3	5/30/2014-10/22/2014

Variable	N	Mean	Std Dev	Min	Max	1st Pctl	5th Pctl	10th Pctl	25th Pctl	50th Pctl	75th Pctl	90th Pctl	95th Pctl	99th Pctl
Temp	5931	22.455	2.673	13.535	26.687	14.9	16.5	18.1	21.2	23.0	24.5	25.3	25.7	26.1
DOsat	5931	57.425	12.127	22.70	94.30	32.9	37.7	40.3	48.2	57.8	67.5	72.5	75.2	83.1
DO	5931	5.010	1.230	1.88	8.70	2.73	3.15	3.38	4.05	4.95	5.93	6.69	6.93	8.03
Turbidity	5931	30.324	44.782	-0.7	834.8	2.6	5.3	7.0	10.6	17.2	28.7	60.3	104.5	240.1
pH	5931	7.647	0.101	7.34	8.06	7.42	7.49	7.53	7.59	7.64	7.69	7.79	7.84	7.93
Cond	5931	720	158	339	1078	386	459	507	588	736	851	905	964	1035
TDS	5931	468	103	220	700	251	298	330	382	478	553	588	627	673
SpCond	5931	758	165	359	1083	407	487	535	624	778	878	988	1028	1050
Sal	5931	0.371	0.084	0.17	0.54	0.19	0.23	0.26	0.3	0.38	0.43	0.49	0.51	0.52
Chl_RFU	5931	0.457	0.316	-0.07	2.68	-0.03	0.06	0.17	0.26	0.39	0.56	0.87	1.04	1.57
Chl_ugL	5931	1.860	1.201	-0.16	10.32	0.01	0.36	0.77	1.12	1.60	2.26	3.45	4.10	6.08
BGA_RFU	5931	-0.144	0.105	-0.24	0.66	-0.22	-0.21	-0.2	-0.19	-0.17	-0.15	-0.07	0.09	0.35
BGA_ugL	5931	-0.144	0.105	-0.24	0.66	-0.22	-0.21	-0.2	-0.19	-0.17	-0.15	-0.07	0.09	0.35

Table 6b. Data sonde summaries for the Grand River site, GR2 at Grand River Sailing Center.

Data Sonde summaries 2014		Edited data, transitions excluded				Grand River sites								
GR2	6/4/2014-11/4/2014													
Variable	N	Mean	Std Dev	Min	Max	1st Pctl	5th Pctl	10th Pctl	25th Pctl	50th Pctl	75th Pctl	90th Pctl	95th Pctl	99th Pctl
Temp	7341	19.770	4.120	7.200	27.376	7.9	11.8	12.6	17.7	21.3	22.8	23.6	24.3	25.5
DOsat	7341	75.543	13.430	28.4	128.7	45.5	52.7	58.6	67.8	75.8	82.6	89.1	99.8	115.8
DO	7341	6.955	1.417	2.47	11.7	4.09	4.68	5.12	5.99	6.84	7.87	8.98	9.35	10.16
Turbidity	7341	23.839	51.876	-0.7	1007.7	0.9	3.3	4.8	7.8	12.7	21.9	36.8	61.5	310.2
pH	7341	7.608	0.233	7.07	8.73	7.14	7.26	7.35	7.47	7.59	7.71	7.88	8.08	8.36
Cond	1341*	418	140	157	783	162	180	199	301	446	513	588	629	711
TDS	1341*	272	91	102	509	105	117	129	196	290	334	382	409	462
SpCond	1341*	445	153	168	764	173	190	211	314	489	548	630	678	715
Sal	1341*	0.214	0.076	0.08	0.37	0.08	0.09	0.10	0.15	0.24	0.27	0.31	0.33	0.35
Chl_RFU	7341	0.961	1.063	-0.09	8.87	0.04	0.13	0.22	0.36	0.60	1.07	2.39	3.38	5.34
Chl_ugL	7341	3.502	3.622	-0.06	30.44	0.36	0.69	0.96	1.45	2.26	3.86	8.38	11.74	18.44
BGA_RFU	7341	0.157	0.324	-0.08	3.47	-0.04	-0.03	-0.03	-0.01	0.02	0.17	0.52	0.82	1.58
BGA_ugL	7341	0.157	0.324	-0.08	3.47	-0.04	-0.03	-0.03	-0.01	0.02	0.17	0.52	0.82	1.58

Lower trophic level (chlorophyll and plankton) samples; OSU contract reports.

Ohio Division of Wildlife personnel collected chlorophyll and plankton samples from as many as nine sites in the lower Cuyahoga River (LR0, LR1 and LR2), the old channel of the river (OC1 and OC2), the harbor inside the breakwall (H1 and H2), and adjacent Lake Erie nearshore sites outside the breakwall (OB1 and OB2) on 13 dates between 4 May and 28 October 2011, on 14 dates between 19 April and 9 October 2012, on 13 dates between 18 April and 2 October 2013, and 10 dates in 2014. Beginning in April 2013, chlorophyll, phytoplankton, and zooplankton were also sampled from two stations (GR1 and GR2) in the Grand River, to allow comparisons of the chlorophyll and plankton from the Cuyahoga River with that of a river that had a smaller ship channel, less shoreline armoring, and a less-developed watershed that influenced water quality in the lower sections of the mainstem river. The lower Grand River is also not designated as an AOC. Analysis of chlorophyll as chl *a* and pheo *a* was completed for all samples collected from the Cuyahoga River from 2011 through 2014 (Figures 18 and 19) and from the Grand River for 2013 and 2014 (Figures 18 and 19), and complete data are presented in Appendix 3.

Microscopic analyses of taxonomic composition, density, and biomass were completed for all of the phytoplankton and zooplankton samples collected in 2011, 2012, 2013 and 2014 (see below), except for 44 samples from stations H1 and OC in 2014. These plankton species observed are summarized in Table 7 (phytoplankton) and Table 8 (zooplankton), presented spatially by date in Figures 20-25, in the Culver et al. (2015) completion report, and data and presentation attached as Appendix 3.

Both rivers generated a wealth of data on the taxonomy and diversity of planktonic life in the rivers and Cleveland harbor site locations. It was apparent from the samples, that while sufficient plankton was being produced and was available in the lower portion of the Cuyahoga River and Cleveland harbor, the types and quantities of high-quality zooplankton for fish forage was lower than those values recorded in the open waters of Lake Erie and in the Grand River. Phytoplankton densities were also greater for the cyanobacteria, and the ratio of cyanophytes (blue greens; mainly *Microcystis*) to chlorophytes (greens) was also greater in the lower Cuyahoga than in the Grand, further exemplifying the impaired conditions. However, no benchmark BUI values have been established to compare study results to levels or standards that reflect quality or impaired conditions.

Table 7. Genera of phytoplankton identified during analysis of samples collected in 2011-2014 from the Cuyahoga and Grand River sites.

Chlorophyta
Actinastrum
Ankistrodesmus
Carteria
Chlamydomonas
Closteriopsis
Coelastrum
Closterium
Cosmarium
Crucigenia
Dictyosphaerium
Dimorphococcus
Eudorina
Franceia
Golenkinia
Kirchneriella
Lagerheimia
Micractinium
Oocystis
Pandorina
Pediastrum
Phacotus
Quadrigula
Scenedesmus
Schroederia
Sphaerocystis
Staurastrum
Tetraedron
Tetrastrum
Westella

Chrysophyta
Asterionella
Coscinodiscus
Cyclotella
Cymbella
Dinobryon
Fragilaria
Gyrosigma
Mallomonas
Melosira
Navicula
Nitzschia
Rhoicosphenia
Stephanodiscus
Synedra

Cryptophyta
Chroomonas
Cryptomonas
Rhodomonas

Cyanobacteria
Anabaena
Aphanizomenon
Aphanocapsa
Aphanothece
Chroococcus
Cylindrospermopsis
Merismopedia
Microcystis
Planktothrix

Pyrrhophyta
Ceratium
Gymnodinium
Peridinium

Table 8. Zooplankton taxa found in 2011-2014 Cuyahoga plankton samples.

Crustacean Zooplankters

Cladocera

Alona spp.
Alonella spp.
Bosmina longirostris
Camptocercus spp.
Ceriodaphnia spp.
Chydorus sphaericus
Daphnia ambigua
Daphnia galeata mendota
Daphnia longiremis
Daphnia parvula
Daphnia pulex
Daphnia retrocurva
Diaphanosoma birgei
D. brachyurum
Eubosmina coregoni
Holopedium gibberum
Ilyocryptus spp.
Kurzia latissima
Leptodora kindti
Leydigia spp.
Macrothrix spp.
Moina spp.
Sida crystallina
Simocephalus spp.

Copepods

Calanoid Copepods

Epischura lacustris
Eurytemora affinis
Leptodiaptomus ashlandi
Leptodiaptomus minutus
Leptodiaptomus siciloides
Skistodiaptomus oregonensis
Skistodiaptomus pallidus
Skistodiaptomus pygmaeus
Skistodiaptomus reighardi
Calanoid copepodites

Cyclopoid copepods

Acanthocyclops vernalis
Diacyclops nanus
Diacyclops thomasi
Eucyclops agilis
Eucyclops speratus
Macrocyclops albidus
Mesocyclops edax
Mesocyclops americanus
Microcyclops rubellus
Paracyclops fimbriatus poppei
Tropocyclops prasinus mexicanus
Cyclopoid copepodites

Harpacticoid copepods

Canthocamptus spp.

Copepod Nauplii

Calanoid nauplii
Cyclopoid nauplii

Rotifers

Ascomorpha spp.
Asplanchna spp.
Brachionus spp.
Collotheca spp.
Conochilus spp.
Euchlanis spp.
Filinia spp.
Kellicottia spp.
Keratella spp.
Lecane spp.
Monostyla spp.
Notholca spp.
Platyias spp.
Ploeosoma spp.
Polyarthra spp.
Synchaeta spp.
Testudinella spp.
Trichocerca spp.

Dreissena veligers

Dreissena polymorpha
D. rostriformis bugensis

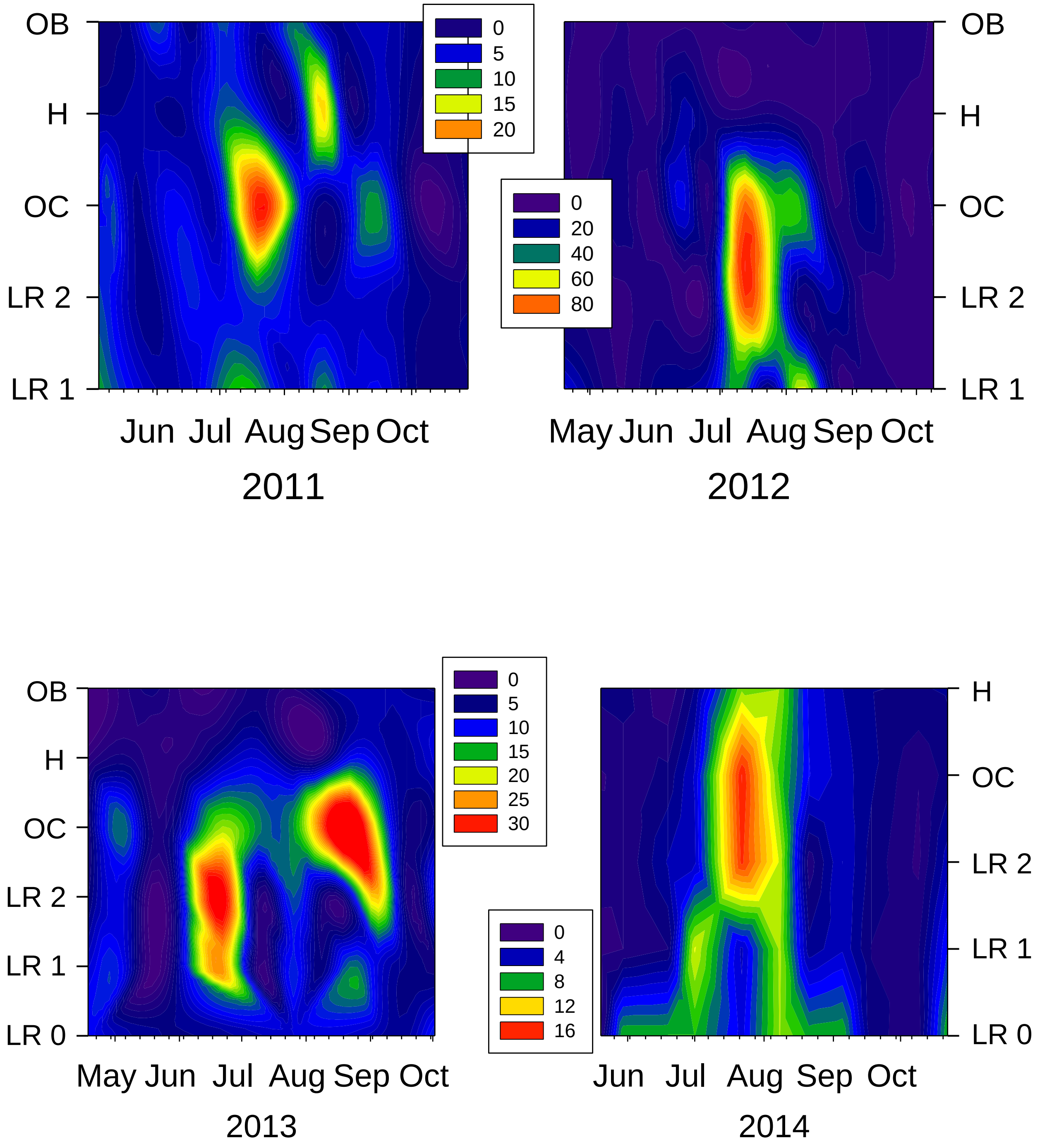


Figure 18a. Temporal and spatial variation in chlorophyll *a* concentration (micrograms/L) in the Cuyahoga River and adjacent areas of Lake Erie, 2011, 2012, 2013, and 2014. Stations are in the lower river (LR0, LR1 and LR2), the Old Channel (OC) of the river, in the Harbor inside the breakwall (H), and in Lake Erie outside the breakwall (OB), except for 2014. Note the differences in scales between years.

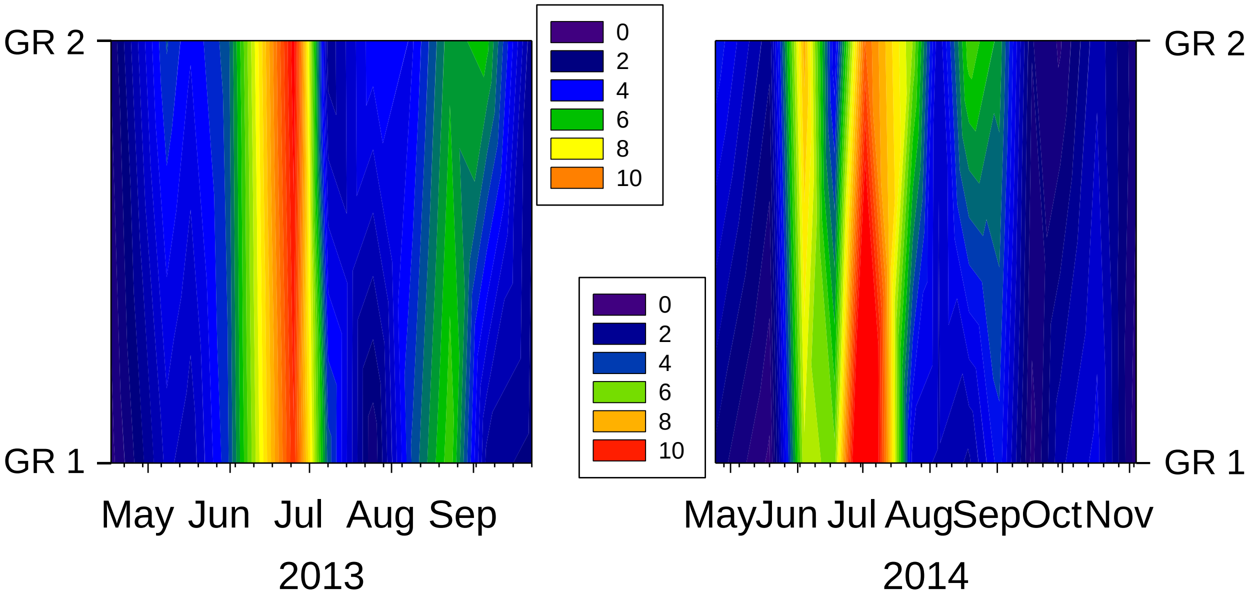


Figure 18b. Temporal and spatial variation in chlorophyll *a* concentration (micrograms/L) in the Grand River, 2013 and 2014.

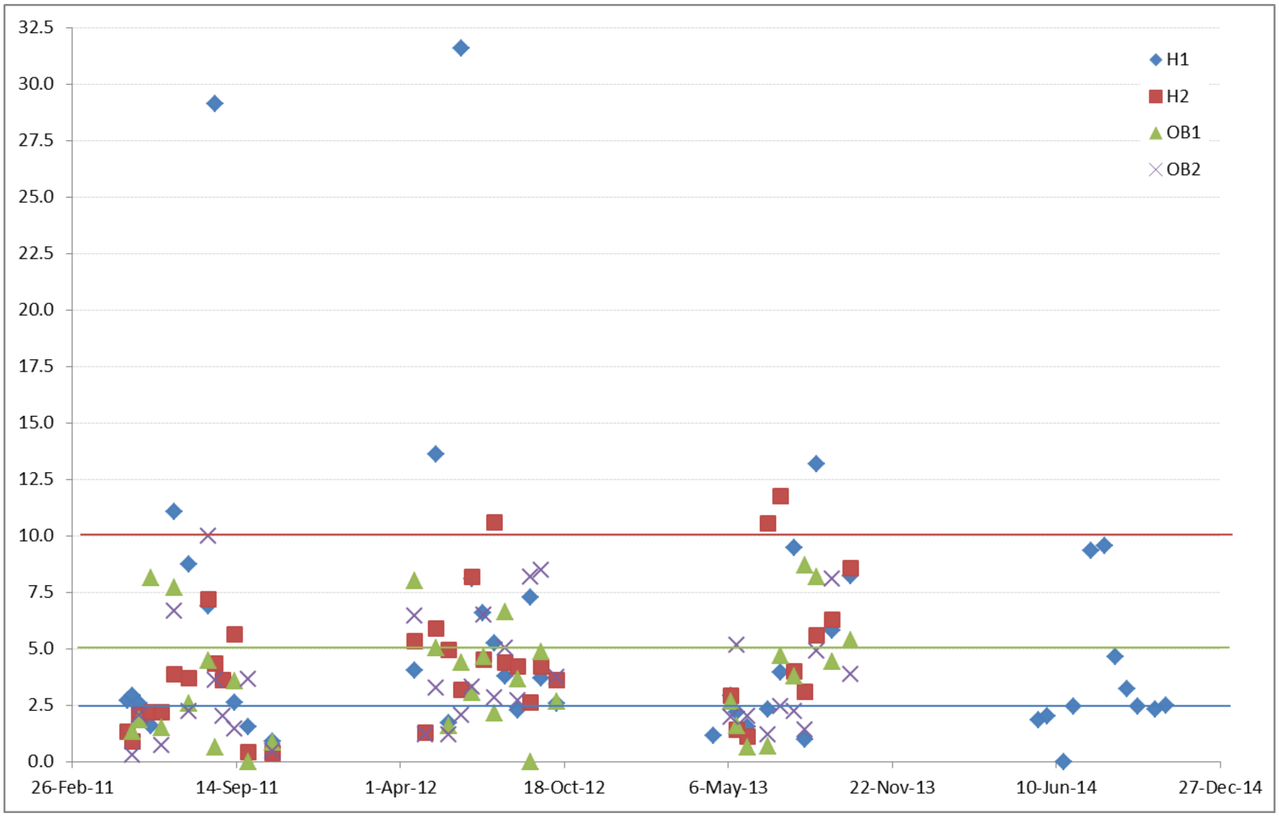


Figure 19a. Chlorophyll-*a* readings (in ug/l) at stations in Cleveland Harbor (H1 and H2) and just outside the Cleveland Harbor breakwall (OB1 and OB2) during project sampling events in 2011-2014. The threshold (range) for oligotrophic conditions is up to 2.5 ug/l (blue line); for mesotrophic conditions, 2.5-5.0 ug/l (green line); for eutrophic conditions, 5.0-10.0 ug/l (red line); and hypereutrophic conditions, above 10.0 ug/l.

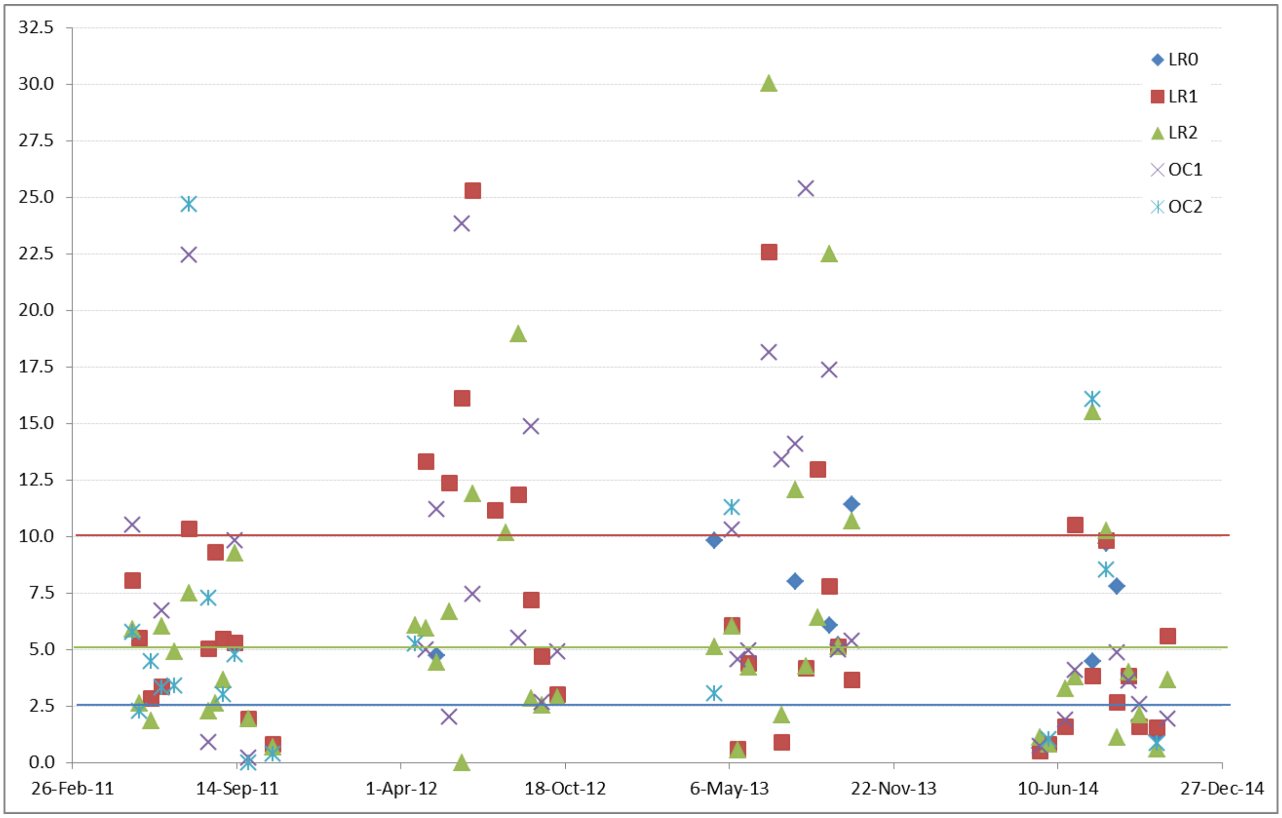


Figure 19b. Chlorophyll-*a* readings (in ug/l) at stations in the lower Cuyahoga River (LR0, LR1 and LR2) and the old river channel (OC1 and OC2) during project sampling events in 2011-2014. The threshold (range) for oligotrophic conditions is up to 2.5 ug/l (blue line); for mesotrophic conditions, 2.5-5.0 ug/l (green line); for eutrophic conditions, 5.0-10.0 ug/l (red line); and hypereutrophic conditions, above 10.0 ug/l.

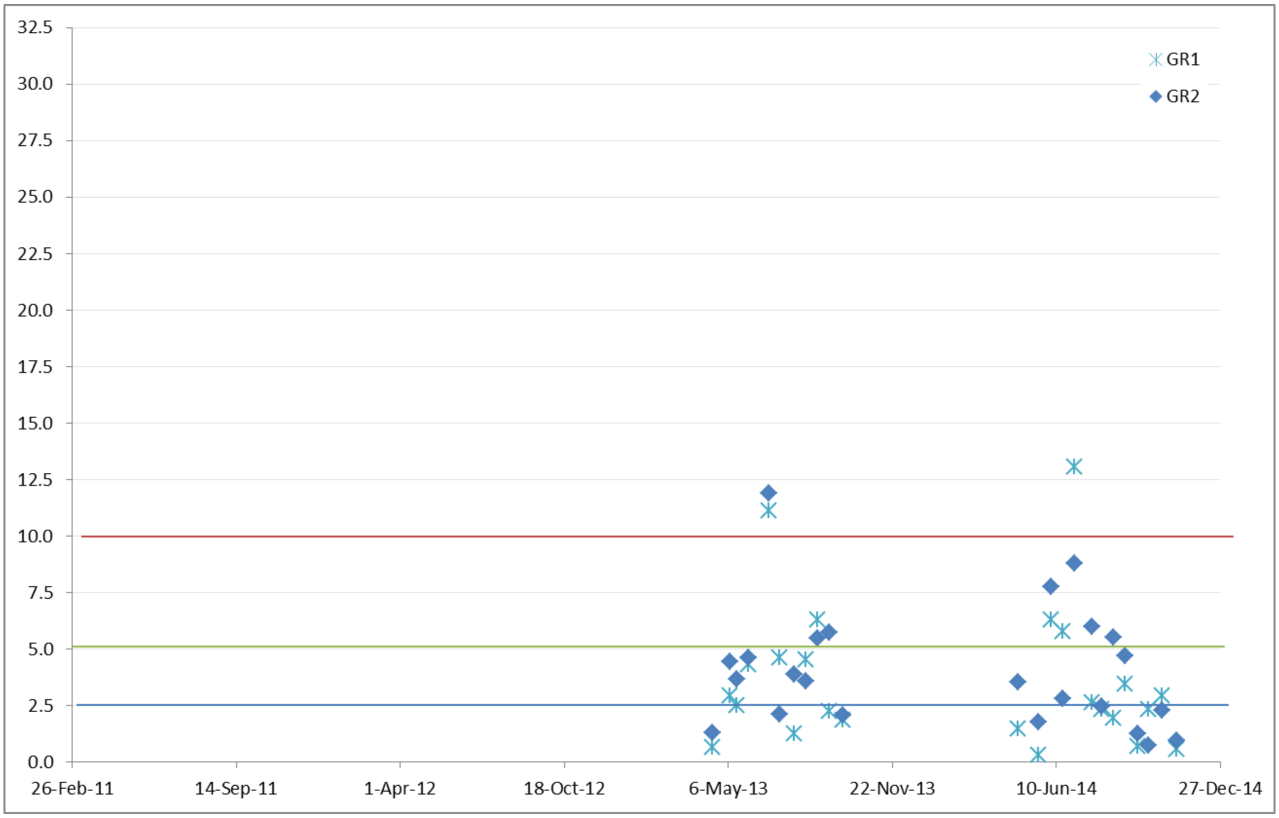


Figure 19c. Chlorophyll-*a* readings (in ug/l) at stations in the lower Grand River (GR1 and GR2) during project sampling events in 2013-2014 for comparison purposes to Cuyahoga River sampling stations. The threshold (range) for oligotrophic conditions is up to 2.5 ug/l (blue line); for mesotrophic conditions, 2.5-5.0 ug/l (green line); for eutrophic conditions, 5.0-10.0 ug/l (red line); and hypereutrophic conditions, above 10.0 ug/l.

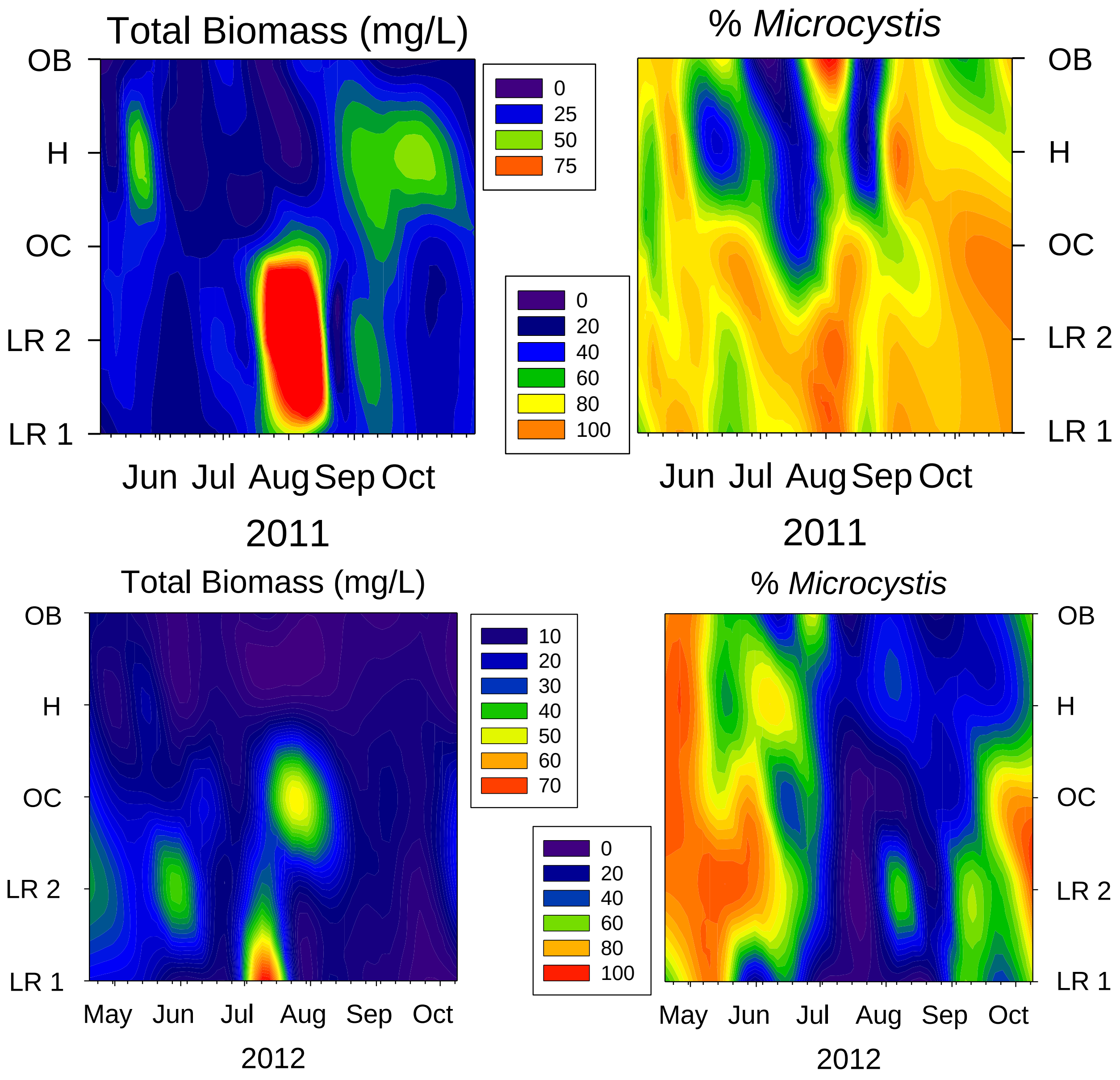


Figure 20. Temporal and spatial variation of phytoplankton biomass (mg wet weight/L) in the Cuyahoga River and adjacent areas of Lake Erie, 2011 and 2012. Much of the phytoplankton in the river was the cyanophyte *Microcystis*, as shown by the % *Microcystis* panels on the right. Stations are in the lower river (LR1 and LR2), the Old Channel (OC), in the Harbor (H), and in Lake Erie outside the breakwall (OB). Note the differences in scales between panels.

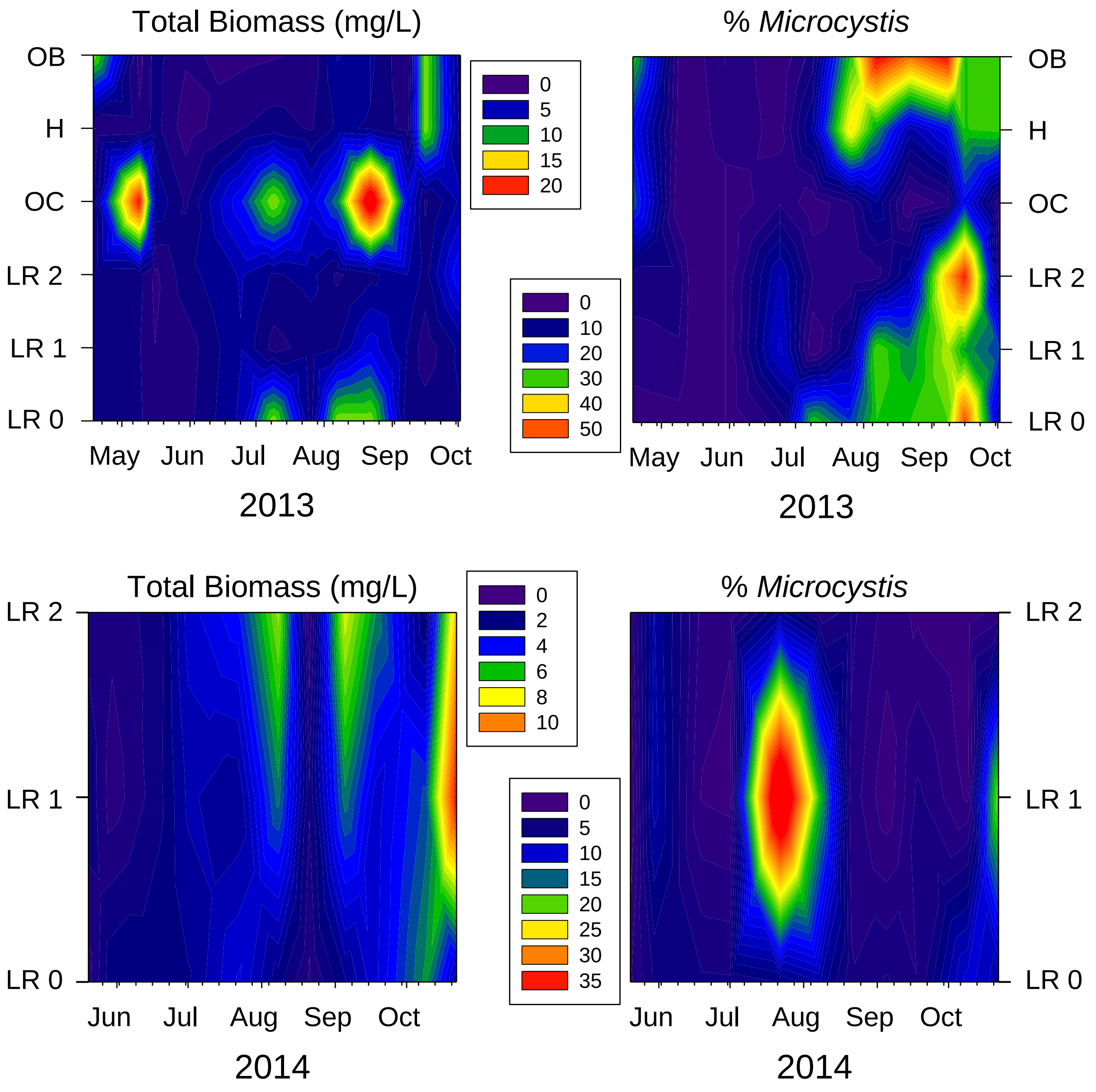


Figure 21. Temporal and spatial variation of phytoplankton biomass (mg wet weight/L) in the Cuyahoga River and adjacent areas of Lake Erie in 2013 and 2014. Stations are as in Figure 3. Much of the phytoplankton in the river was the cyanophyte *Microcystis*, as indicated by the % *Microcystis* panels shown on the right.

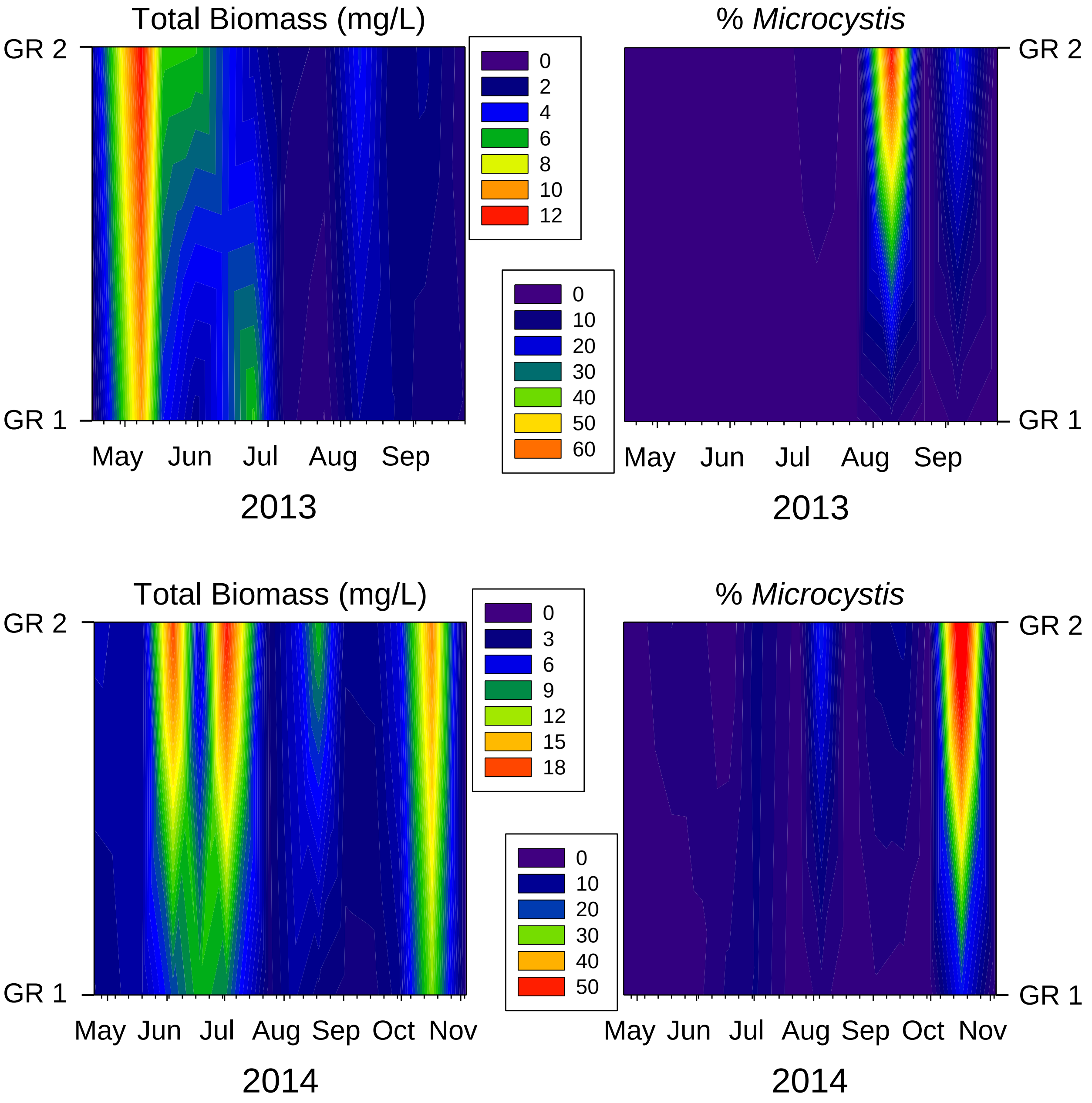


Figure 22. Temporal and spatial variation of phytoplankton biomass (mg wet weight/L) in the Grand River in 2013 and 2014. Isopleths show less detail than those in Figures 3 and 4 because there were only two sampling stations in the Grand River. Much of the fall phytoplankton in the river was the cyanophyte *Microcystis*, as indicated by the % *Microcystis* panels shown on the right. Note the scaling is different between years.

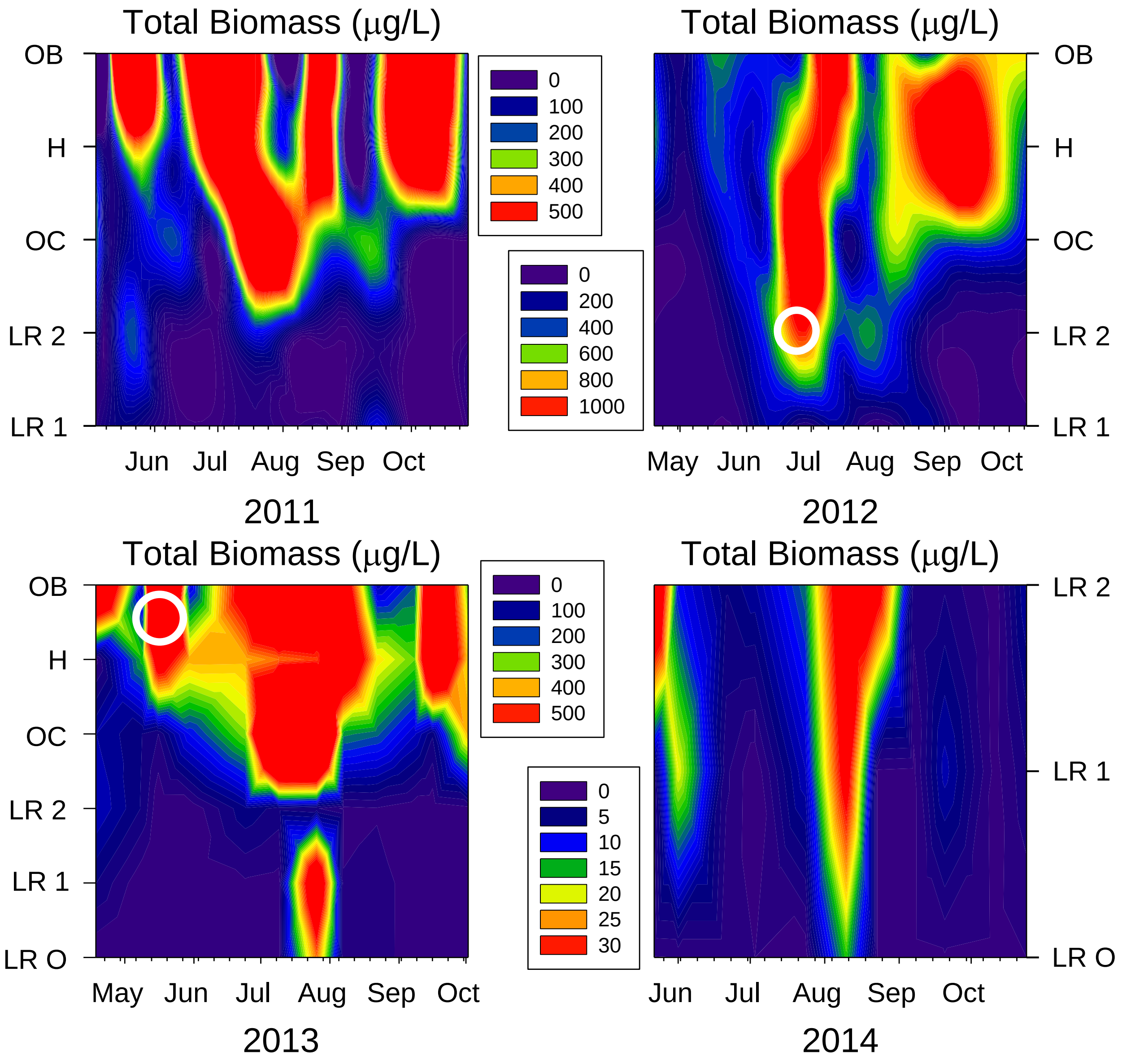


Figure 23. Temporal and spatial variation of total zooplankton biomass (µg dry weight/L) in the Cuyahoga River and adjacent areas of Lake Erie, 2011, 2012, 2013, and 2014 . Note the scaling is different between years. The white circles represent exclusion from the graph of extremely high biomasses (>36,000 µg dry weight/L) due to an extreme abundance of rotifers found at site LR2 during the last week of June 2012 and > 1400 µg dry weight/L outside the breakwall in mid-May 2013. The actual values can be found in the 2012 and 2013 zooplankton biomass tables (Tables 10 and 11).

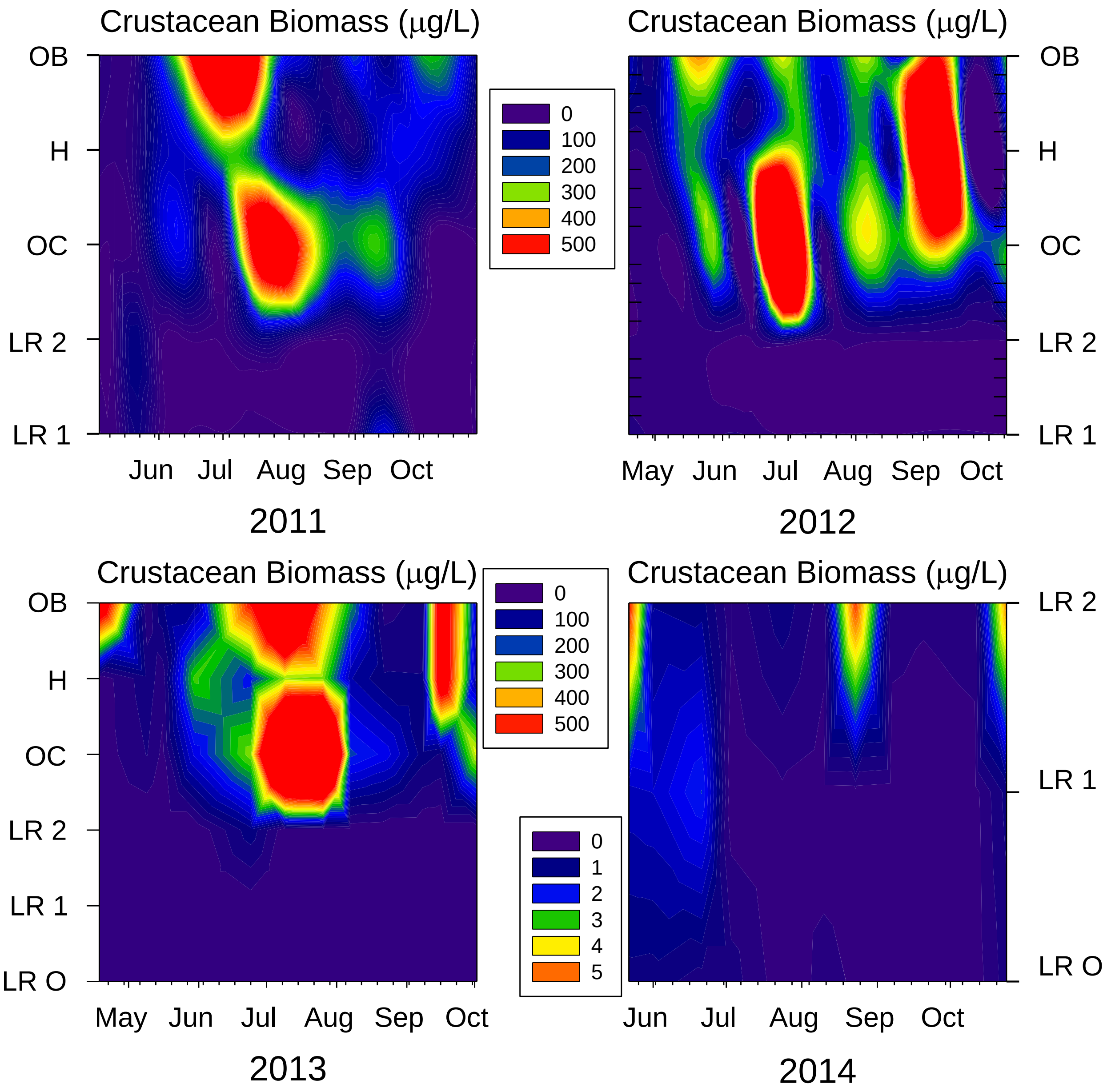


Figure 24. Temporal and spatial variation of Total Crustacean Biomass (µg dry weight/L) (excluding rotifers and veligers) in the Cuyahoga River and adjacent areas of Lake Erie, 2011, 2012, 2013, and 2014 (compare with Figure 5). Much of the biomass in the Lower River sites is from rotifers and veligers, whereas in the Old Channel the abundance of crustacean zooplankton exceeds that of non-crustacean zooplankton over the entire sampling season in 2011, 2012, and 2013. Fewer samples were analyzed from the 2014 OB, H and OC sites, affecting the appearance of the isopleths.

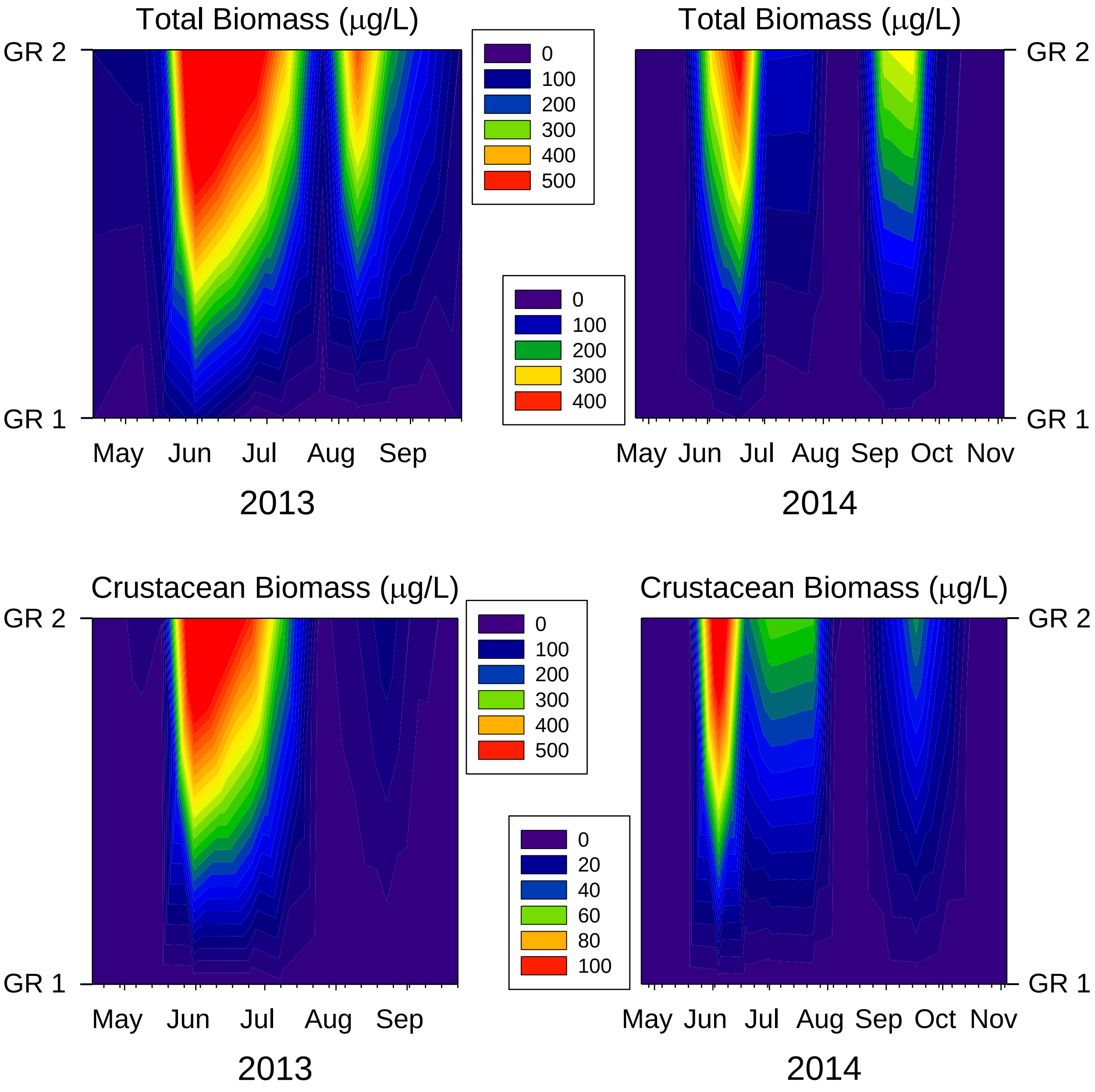


Figure 25. Temporal and spatial variation of Total Zooplankton Biomass (µg dry weight/L) in 2013 and 2014 (Upper Panels) and Crustacean Zooplankton Biomass (Lower Panels) in the two stations in the Grand River.

Lower trophic level (benthic) samples

Ponar grab sampling at Cuyahoga River sites resulted in capture of several types of aquatic invertebrates, several of which were invasive, nuisance species. Catches were dominated by midge larvae (chironomids), and included zebra and quagga mussels and fragments, the Asian clam *Corbicula*, gastropods (snails, and shell fragments), fingernail clams (sphaeriids), caddis fly larvae (tricopterans), aquatic worms and leeches. Diversity, abundance and species quality were relatively fair to poor, but these results were expected for the actively dredged area in the ship channel of the lower river. Ponar sampling at Grand River benthic sample sites in 2013 resulted in no invertebrates captured, as material was recently-dredged hardpan clay (at GR2) or solid glacial cobbles and small boulders mixed with gravels (at GR1).

The Northeast Ohio Regional Sewer District also completed benthic evaluations during this time period using Hester-Dendy samplers in our Cuyahoga River Study Area (NEORSD 2012 and 2013, Seth Hothem, NEORSD, pers. comm.). Their methods allowed a finer scale of quantitative analyses, and determination of either Ohio EPA’s Invertebrate Community Index (ICI; OEPA 1987a, Ohio EPA undated) or Lacustuary Invertebrate Community Index (L-ICI; OEPA 1987a, Ohio EPA undated). The ICI and L-ICI both consist of ten community metrics (Table 12), each with four scoring categories. Summing individual metric scores result in the overall score and this allows comparisons of the community against Ohio EPA’s reference sites for each specific eco-region.

NEORSD ICI and L-ICI scores for the four locations sampled in the Study Area (RMs 7.0, 5.9, 2.7, and 0.2) during the 2011-2014 time period ranged from poor (downstream at the mouth) to fair (at sites located in the middle and above of the ship channel), to fair to marginally good at the location sampled above the ship channel. Most of the invertebrate samples were dominated by midges. Their samples, like ours, contained few tolerant or sensitive species, and those densities were greatest above the ship channel. NEORSD samples met or partially attained criteria for warmwater habitat above the GLRI project Study Area, but our and their results show that AOC area non-attainment was due to the limited available habitat in the study area.

Aquatic vegetation surveys

Field assessments of aquatic vegetation were made in the Cuyahoga River in 2012 and 2013 and comparison assessments were noted in the Grand River in 2013 (Figures 26 a-e). There was essentially no submersed aquatic vegetation observed in the main channel of the Cuyahoga River from the first riffle (LR0) downstream to the mouth of the river. There was sparse to locally dense aquatic vegetation found from June into early fall in the side channels and marina dockage areas in the Cuyahoga River’s Old Channel (near station OC1) and in the shallow water areas at the mouth of Kingsbury Run (located downstream of I-490 and upstream of Marathon Bend and the W 3rd Street bridge). There was also moderate to dense aquatic vegetation in the marinas located in Cleveland harbor.

Moderate to sparse aquatic vegetation was observed along the inside edge of the Cleveland harbor east-west breakwalls and inside the breakwalls in Cleveland Lakefront Park locations associated with the Edgewater and Gordon Park boat ramps and marinas. Most of the aquatic vegetation was invasive or nuisance species such as *Myriophyllum spicatum,* Eurasian milfoil, coontail, *Ceratophyllum demersum*, and the filamentous algae *Cladophora*. Aquatic vegetation that would be classified as good fish habitat such as eel grass *Vallisneria* and pond weed *Potamogeton* species were found in multiple locations, but were not dominant. There were sparse clusters of *Potamogeton* along the inside of Cleveland harbor breakwall that provided good fish habitat. There were no observations or samples of the invasive species *Hydrilla* noted in any of our surveys in the study areas in 2012 and 2013.

Grand River locations had a bit more aquatic vegetation in the margins of the river along the river banks and in marinas. Again, most of the vegetation was invasive like milfoil, but coontail, pond weeds, and eel grass were also prevalent.

Emergent vegetation was more established in the Grand River, as there were fewer areas where the river banks were fortified by concrete, wood cribs and metal sheetpile. There were washout areas or fan-shaped lenses along the Cuyahoga River and Old Channel where banks were mostly topsoil/ sediment or spoils with shallow water immediately adjacent. In these areas, sweet flag, pickerel weed, cat-tail *Typha* spp., reed grass *Phragmites australis*, swamp (rose) mallow (*Hibiscus* spp.), and other wetland emergent vegetation species were present. These areas aided near-shore habitat complexity and stability and served as a small buffer to the many miles of hardened shore armoring. Recently initiated habitat improvement projects in the I-90 bridge area also sought to increase the amount of shoreline shallow habitat. These locations were recorded geographically and have been presented in Figures 27a through e and Figures 28a and b. Due to the amount of shore armoring throughout the ship channel, the annual dredging throughout the navigation channel to a uniform depth of at least 23 feet, and the sediment load found in the water column in the lower river, there is little opportunity for a complex aquatic vegetation community to be supported along the margins of the river in the navigation channel. This impairment may have a direct effect on the health of the fish communities and life stages in the river and harbor.

Figure 26a. Kingsbury Run where aquatic vegetation was observed in 2012 (shaded area in green).

Figure 26b. Scranton Rd. peninsula/old Scaravelli marina where aquatic vegetation was observed in 2012 (shaded area in green).

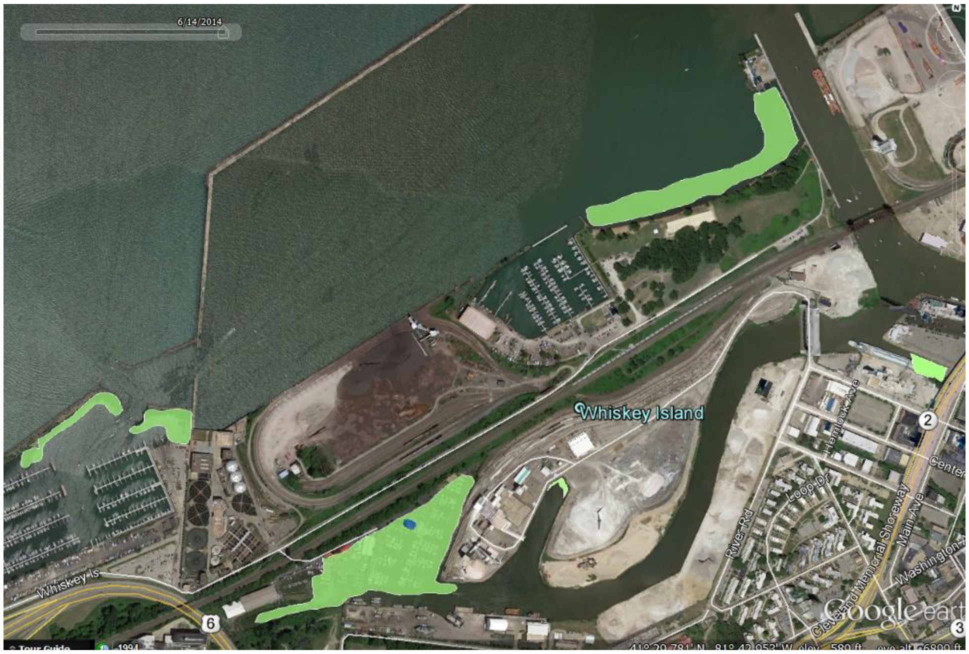


Figure 26c. Old Channel (lower) and western harbor locations where aquatic vegetation was observed in 2012 (shaded areas in green). Sparse vegetation (mainly *Cladophora*) was noted along the inside portion of the outer breakwall).

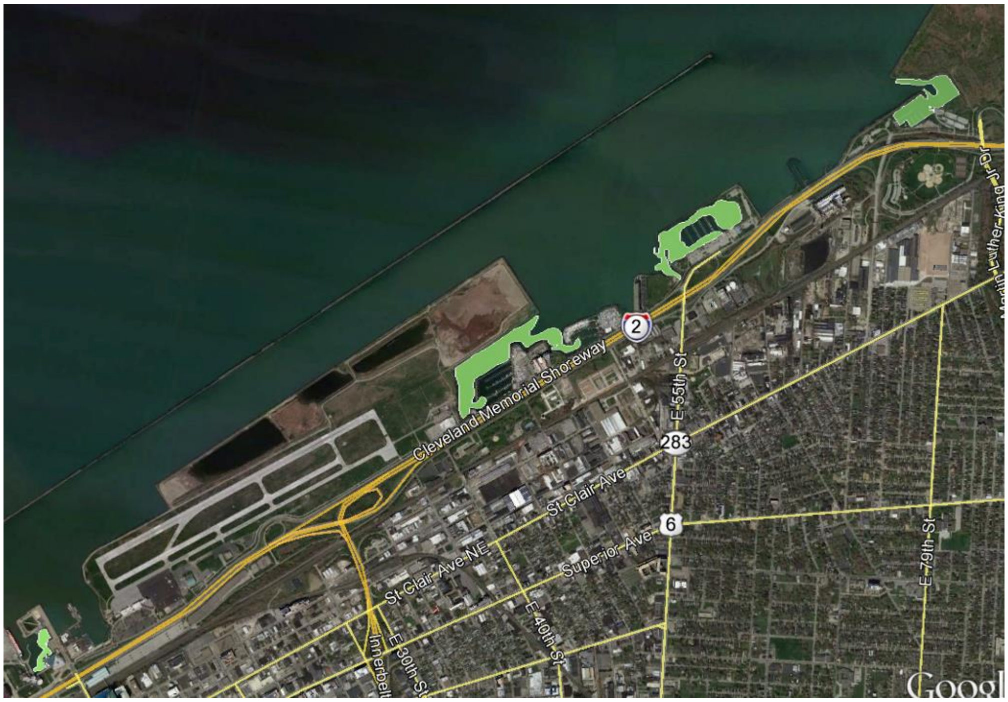


Figure 26d. Middle harbor and eastern harbor locations where aquatic vegetation was observed in 2012 (shaded areas in green). Sparse vegetation (mainly *Cladophora*) was noted along the inside portion of the outer breakwall).

Figure 26e. Grand River locations where aquatic vegetation was observed in 2013 (shaded areas in green).

Figures 27a-e (below). Shallow water, riverbank openings, and associated habitats.

27a. Middle river area near St Rt 82 dam.

27b. First riffle area.

27c. Rip rap area at Arcelor Mittal.

27d. Open fan-shaped area devoid of sheetpile exhibiting established shoreline vegetation; Cuyahoga River right descending bank below the Arcelor Mittal main plant, river mile 5.

27e. Nearshore vegetation cover and development at Irishtown Bend.

Figures 28 a and b. Habitat improvement projects that increase shallow water habitat: Scranton Road Project (left) and I-90 ODOT Project (right) shown from Google earth.

Fish assessment surveys

Larval fish sampling

Attempts to sample larval fish were completed at each sampling station from April through July. Larval fish were sampled each year, with varying degrees of success (Table 9). Most of the larval fish captured were Emerald Shiner or Gizzard Shad, two common fish species that are an important part of the forage base for piscivorous fish in Lake Erie, lower rivers, harbors and nearshore areas. The presence of larval White Bass, White Perch, Yellow Perch, suckers and redhorses are positive notes.

Table 9. Larval fish captured in ichthyoplankton trawls performed for this project.

Summary of larval fish captured

		Number of larvae collected				Grand R.	
Spp Code	Species	2011	2012	2013	2014	2013	2014
63	Gizzard shad	20	152	62	246	6	10
121	Rainbow smelt	0	0	1	0	0	0
170	Shorthead redhorse	0	0	1	0	0	0
171	Golden redhorse	1	0	0	0	0	0
163	White sucker	1	0	0	0	0	0
196	Emerald shiner	1,644	835	187	9	0	15
200	*Notropis* spp.	0	0	23	0	0	0
291	Trout-perch	0	0	1	0	0	0
301	White perch	0	0	1	0	0	0
302	White bass	4	11	0	0	0	0
331	Yellow perch	0	0	3	0	0	0
361	Brook silverside	1	0	0	0	0	0
366	Round goby	0	1	0	0	0	0
371	Freshwater drum	3	0	0	0	0	0
0	eggs	11	46	22	0	0	0
	N samples w/ larval fish	33	48	21	5	1	3

Juvenile and adult fish sampling by electrofishing

We sampled juvenile and adult fish populations using electrofishing in Cuyahoga River in 2011-2014 and in Grand River in 2013 and 2014. Two sample dates were completed each year in the Cuyahoga R in 2011- 2014. One sample date was completed in the Grand R in 2014. Poor weather and river conditions and availability of sampling equipment limited the scope of our sampling activities. Tallies of species and numbers of fish caught by year are presented in Tables 10a-c. Catches were dominated by forage fish (shiners and shad) and rough fish (suckers, redhorse, carp), but there were substantial catches of sport and commercial fish such as basses, sunfish, and catfishes. Better catch rates for these sought-after fish species were noted in areas where habitat was significantly different from the standard sheetpile and common dredged depth (greater than 20 feet immediately adjacent to the shore). It was apparent that rip-rap, shallow edge, and habitat improvement areas exhibited better catches for these species.

In comparing our fish sampling results to those obtained by NEORSD, we saw similar overall results in the ship channel and lower river habitat area for species composition, overall fish catches, and fish community index values of IBI and MIwb. In general, our mean IBI scores by station and year for Cuyahoga River and Old Channel sites were mostly in the fair range (24-27; Appendix 4). Our harbor fish IBI scores from along the outer breakwall were in the good range (30-38; Appendix 4), and reflected presence of transient (native) lake species in better, complex shallow water habitats that included aquatic vegetation. It was also noted that the fish composition, fish densities and index scores for NEORSD sample sites above our study area, and above tributaries like Mill Creek, Big Creek and the Southerly WWTP, were generally higher for IBI and MIwb, showing slightly better fish population trends in the areas upstream of the dredged ship channel (Appendix 4).

Examining fish health in the study area, 2.5-3.6% of our fish annually measured by crews during electrofishing exhibited DELTs or anomalies (Appendix 4). By transect electrofished, the proportion of DELTs ranged from 0.0 to 10.1%, and the calculated %DELTs over all four years was 3.1%. The highest occurrence (10.1%) was observed during a prolonged seasonal, early-spring gizzard shad die-off; the next closest high value was only 6.9%; most were in the range of 2-4%. These values were in the range of DELTs observed by NEORSD during their 2011-2014 sampling in the study area: 0.00-4.05%, mean: 1.22%. The ODW values could have potentially been much lower if more fish were handled and examined after each electrofishing pass, instead of estimating numbers of the few fish species observed stunned at the water surface in great abundances; as this was the case of seasonal super-abundances of gizzard shad and emerald shiners at select locations. NEORSD also saw similar to lower DELTs percentages in their sampling areas above this project's study area.

Table 10. Electrofishing results in the study area completed by ODW for this project.

Fish Species and numbers of fish captured by date for Cuyahoga River electrofishing in 2011.

	Date						
Species	14-Apr-2011	21-Apr-2011	5-May-2011	25-May-2011	30-Jun-2011	25-Oct-2011	18-Nov-2011
Gizzard shad	1,629	171	62	310	148	260	2,406
Steelhead trout	6						
Northern pike				1			
Quillback	1		1	3	1	22	
White sucker	43	3	2	20	1		2
Hogsucker				4			
Smallmouth buffalo				1		2	
Spotted sucker			2				
Golden redhorse	3			30	1		
Shorthead redhorse					1	1	
Goldfish					1	1	
Common carp	35	6	47	19	10	35	32
Grass carp						1	
Golden shiner					10	1	
Emerald shiner	237	428	303	315		45	86
Spottail shiner		1		1	1		
Yellow bullhead					1		
Black bullhead					1		
Brown bullhead				1		1	
Channel catfish	4		9	12	5	9	3
Trout-perch			1				
White perch				11	4		
White bass				16	8		
Rock bass	1	3	2		6		
Pumpkinseed sunfish		2	1		13	1	
Bluegill		1	2		5	3	
Smallmouth bass					4	1	
Largemouth bass		2	2	2	11	9	
Walleye				1			
Brook silverside					22		1
Freshwater drum			4	3	2	1	

Table 10 continued.

Fish Species and numbers of fish captured by date for Cuyahoga River electrofishing in 2012.

Species	12-Apr-2012	17-May-2012	8-Aug-2012	9-Nov-2012	23-Aug-2012 *
Gizzard shad	23,353	204	400	2,148	47
Steelhead trout	3				
Northern pike					1
White sucker	106	14	12	10	1
Hogsucker			1	1	
Smallmouth Buffalo			10		
Spotted sucker		2	2		2
Golden redhorse		6	3		
Shorthead redhorse		1			1
Goldfish		3			2
Common carp	61	26	44	5	22
Golden shiner		12	7	1	5
Emerald shiner	54,283	231	463	70	2,118
Longnose gar					1
Black bullhead			1		
Brown bullhead		1			5
Channel catfish	1	3			
White perch		1	5		4
White bass		32			
Rock bass				1	7
Green sunfish				2	
Pumpkinseed sunfish		4	12	4	8
Bluegill	1	3		5	26
Smallmouth bass			4		5
Largemouth bass	3	33	18	9	174
White crappie		1			1
Yellow perch					3
Walleye					2
Logperch					3
Brook silverside				19	
Round goby					25
Freshwater drum	6	10			73

* harbor

Table 10 continued.

Fish species and numbers of fish captured by ODW crews via electrofishing during 2013 and 2014 in the Cuyahoga River and Grand River study areas.

Cuyahoga River	Species	Date				**Grand River**
Species	Code	26-Apr-2013	18-Oct-2013	5-May-2014	15-Aug-2014	24-Apr-2014
Gizzard shad	63	9,409	152	14	169	1
Steelhead trout	76	3	1			18
Northern pike	131					
Quillback	161					10
White sucker	163	20	18	5	4	300
Hogsucker	165	1	5			
Bigmouth Buffalo	166		1	1	1	5
Spotted sucker	167		5	1	1	3
Silver redhorse	168		1			
Golden redhorse	170		2		3	19
Shorthead redhorse	171		2		2	14
Goldfish	181	2	1		4	
Common carp	186	24	35	18	76	4
Golden shiner	194			1	9	
Emerald shiner	196	33	581	519	96	557
Longnose gar	211			1		
Black bullhead	231		1	1	4	
Brown bullhead	233		1	1	2	
Channel catfish	234	9	4	15	3	1
Trout-perch	291	1				
White perch	301		126		20	
White bass	302			1	1	1
Rock bass	311	4	7		3	1
Green sunfish	312	1			2	
Pumpkinseed sunfish	313	2	1		3	
Bluegill	314	3	5		14	1
Smallmouth bass	316	1	6		6	9
Largemouth bass	317	2	14	1	7	1
White crappie	318		1			
Sunfish, general/hybrid	320	3				
Warmouth	323	2				
Yellow perch	331					1
Walleye	334					
Logperch	342					
Brook silverside	361					
Round goby	366					
Freshwater drum	371	21		2		41
Grass Carp	999	2	2			

Hydroacoustic (and camera) habitat and fish evaluations

We employed side-scan sonar techniques to map depths, depth contours, and bottom types in the Cuyahoga and Grand study areas. We evaluated several different types of mapping methods, but the Humminbird side-scan sonar unit with Dr. Depth and DeepView software packages proved to be the simplest and most straight forward way to produce fast, simple contour maps for output and display of river and harbor conditions. The habitat was not complex, and depths fairly uniform, which makes completing these analyses and producing report graphics simpler with this method compared to more powerful, time and computing space consuming methods. Greater depths, more complex habitat, and finer analysis scales including statistical quantification of habitat types would most likely require these better (more expensive) echosounding equipment and more detailed analysis packages. Other analysis packages will need to be explored in the future, as Dr. Depth was acquired by another company in 2013, with no customer support or transition to an alternate analysis package.

In comparing the software packages for use with the Humminbird data, both Dr. Depth and Deep View provide images of the bottom sediments with geo-referencing of latitude and longitude. Deep View presents the images in a uniform "waterfall" pattern with the water column shown in the vertical center of the path taken and the data gathered as a rectangular image that can be scrolled through from beginning to end (Figures 29 a and b). A zoom feature allows the user to zoom in on habitat features, and a ruler allows you to measure distances and sizes of observed items of interest. The drawback is the data object is fixed in waterfall frame; it is a rectangular object even if the path was sinuous. Dr. Depth on the other hand, has georeferenced data outputs that allow you to overlay your results on Google maps for a more realistic display for spatial reference. For that reason alone, most sidescan maps were produced in Dr. Depth software. The lack of areal and GIS statistical analyses limited analytical reporting.

These maps that were generated in Dr. Depth highlight the differences between dredged and un-dredged areas in both rivers and the lack of depth complexity and bottom type diversity in the lower Cuyahoga river channel (Figures 30a-h, Figures 31a-b). The Grand River not only has a smaller segment (area and volume) of dredged river/ship channel, but the Grand also provides some shallow water refugia adjacent to the dredged areas along the river banks. There are varying degrees of complexity associated with the rich dataset gathered in this and the GLRI project, so we can generate multiple products based on what the investigator/recipient's needs are (see Figure 32 as an example).

Habitat mapping using the Humminbird side-scan sonar and Dr. Depth mapping software also allowed habitat and bottom maps to be generated for the study areas. These maps generated showed the contrast between the bottom types, available habitat, and nearshore area features in:

- Cleveland harbor and the breakwalls (Figures 33 a-d)
- the dredged areas of the lower Cuyahoga River and Old Channel (Figures 33 e-k)
- the area immediately above the Cuyahoga ship channel (Figures 33 l-m)
- the area around the first riffle on the Cuyahoga River (Figure 33 n)
- comparison areas on the Grand River (Figures 33 o-q).

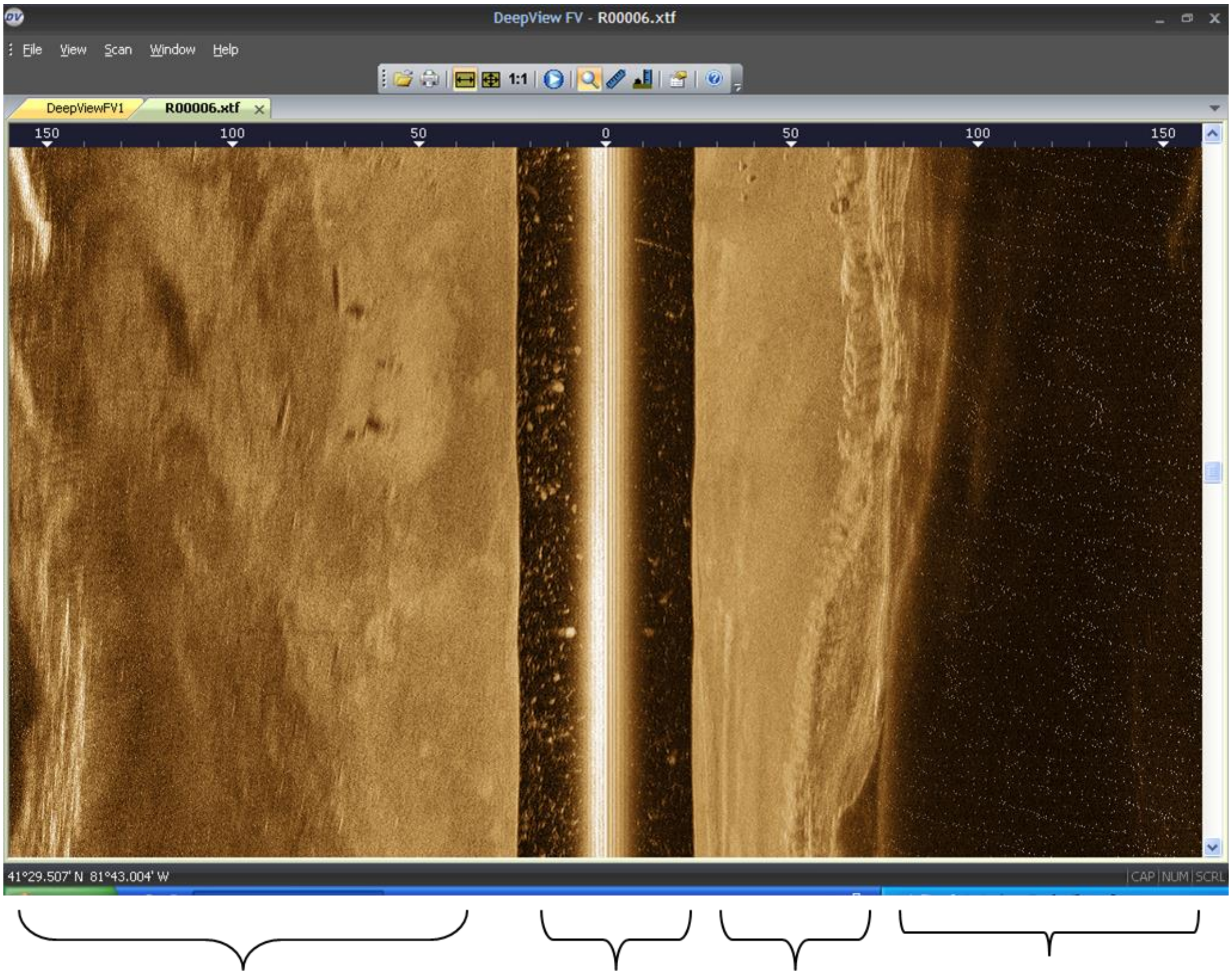
We also employed hydroacoustic techniques to evaluate fish distributions and densities in the lower portion of the Cuyahoga River and Cleveland harbor as planned. These down-looking acoustic techniques can enumerate fish densities in the water column based on return signals from different frequencies received in the sampling process. Our samples in the harbor gave somewhat satisfactory results, but those transects in the river were severely hampered by suspended sediments and excessive turbidity resulting in poor images and incomplete data acquisition (Figures 34a and b). The poor results forced us to abandon this method to examine fish densities in the river.

QHEI and other evaluations of habitat

The complete dataset that accompanies this final report contains the raw side-scan data acquired during the project, associated working data files for the mapping programs, and picture files generated from the analysis programs. While we tried to employ video and still cameras to record in-water habitat and bottom types, the lack of water clarity and high degree of turbidity/ suspended solids caused us to abandon these efforts for further emphasis on the side-scan sonar techniques.

We compared Qualitative Habitat Evaluation Index scores obtained at study areas in this project with those calculated by NEORSD in their annual Environmental Monitoring projects (NEORSD 2012, 2013). Comparisons of QHEI scores between ODW and NEORSD scorers in similar locations in the ship channel and just above it near the first riffle were not significantly different (Appendix 4). QHEI scores for both studies were in the fair to poor ranges in the ship channel (20s-40). NEORSD and our QHEI scores were significantly higher in the area upstream of the ship channel (60s-mid 70s); evidence of the greater habitat diversity and better riffle/pool quality exhibited upstream of the ship channel (Appendix 4).

Lacustuary (L-) QHEI scores for Cleveland Harbor stations H1 and H2 were lower than those stations immediately outside of the breakwall at OB1 and OB2. Station H1 L-QHEI score at 41 was only slightly lower than the outer breakwall locations (45) due to the effects of Wendy Park and the associated beach and shallow water areas that promoted vegetation. Station H2 in the eastern part of the harbor had more shore hardening and less shallows resulting in a much lower L-QHEI score (22) and relatively poorer habitat diversity. Regardless of score variability, L-QHEI scores can range from 0-100, so these recorded values in the Cleveland harbor area represent scores in the middle to low end of the range that exhibit fair to poor natural conditions for lacustrine aquatic habitat.



41°29.507' N 81°43.004' W

Sediment to Port (left) side of boat.

Water Column – boat is at centerline

Sediment to Starboard (right) side of boat.

Black: no depth; elevation above the surface of the water.

Figure 29a. Illustration of Humminbird sidescan data acquired from Cuyahoga River and produced by the DeepView FV program. The figure shown is a portion of the complete XTF file, and georeferencing data from the cursor location in the program is shown in the lower left of the figure.

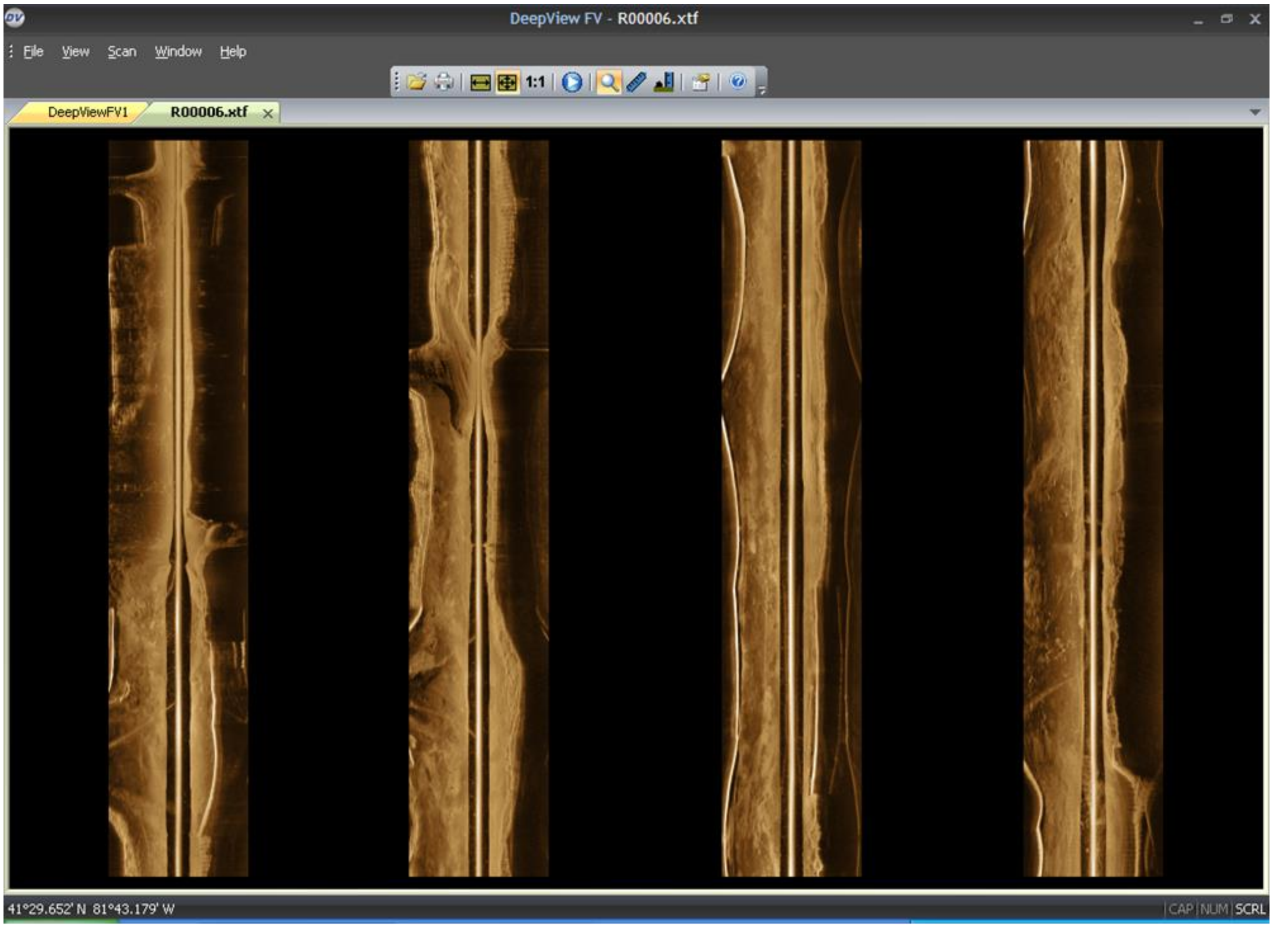


Figure 29b. Illustration of Humminbird Sidescan data acquired from a Cuyahoga River transect and produced by the DeepView FV program. The figure shown is a complete presentation of data recorded and translated into a "waterfall projection" format for the complete XTF file, and geo-referencing data is available from the cursor location in the program and is shown in the lower left of the figure (rather than the data being displayed overlaid on a geo-referenced map).

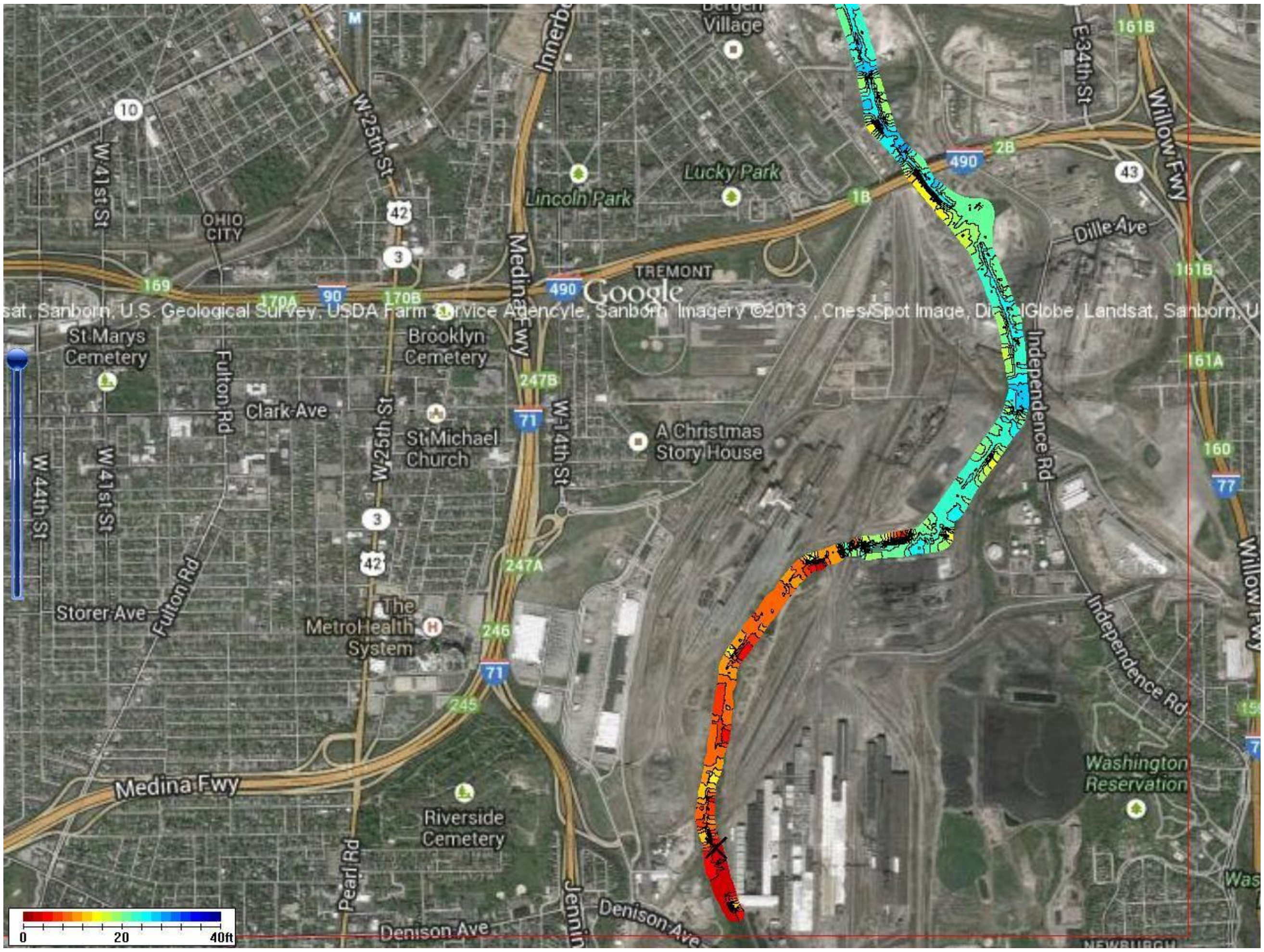


Figure 30a. Depth contour map showing depth differences between the 1st riffle (at map bottom) and downstream of I-490 (at map top) on the Cuyahoga River. The depth change illustrated by the color transition from reds and oranges to blues greens and yellows represents the upper end of the ship navigation channel. Humminbird side-scan sonar data presented with Dr. Depth mapping program and overlaid on Google Earth map.

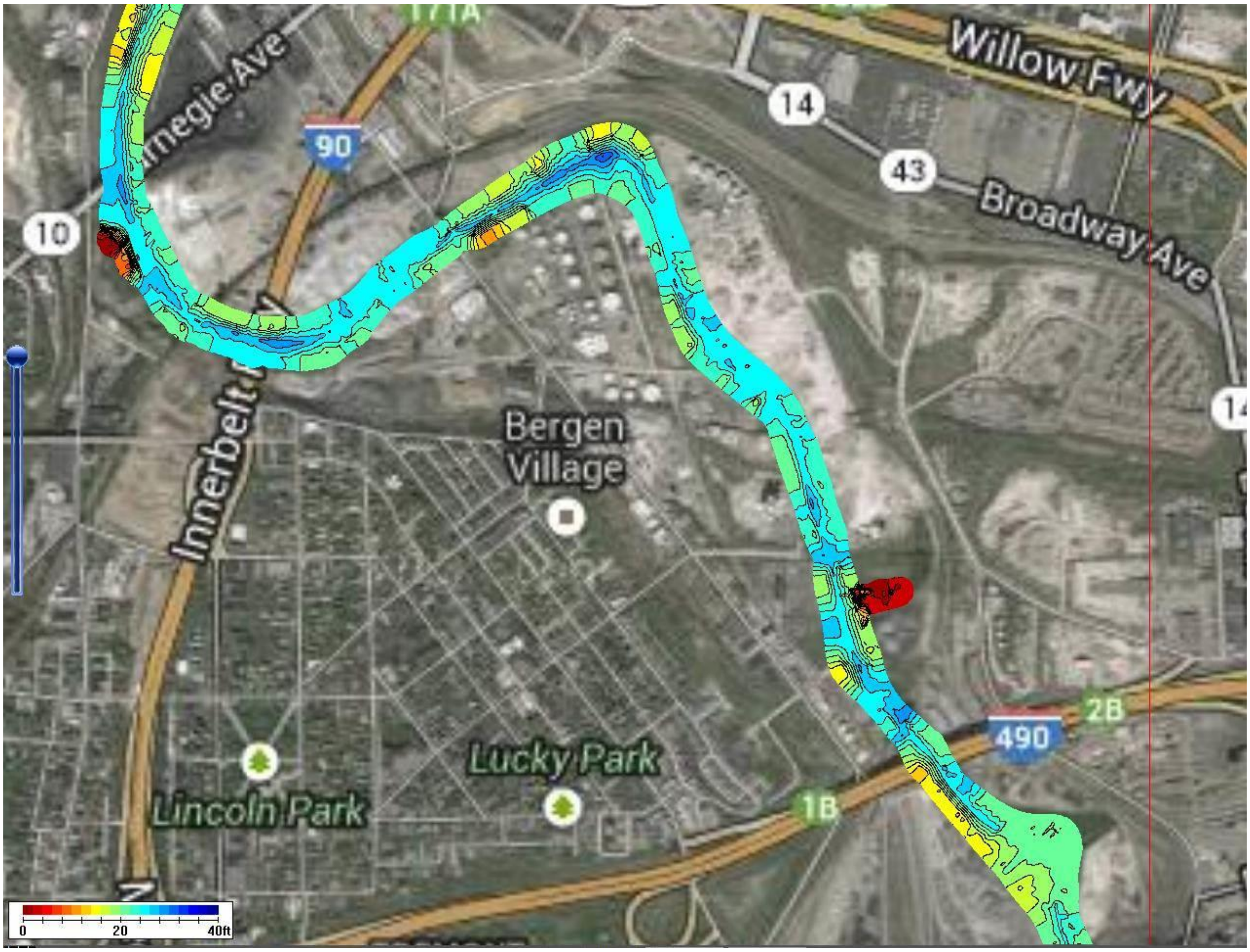


Figure 30b. Depth contour map showing depth differences between I-490 (at map bottom) and downstream of I-90 (at map top) on the Cuyahoga River. The lower shallow area in red is Kingsbury Run a tributary to the Cuyahoga River. The upper red area is the old Scaravelli marina area where a habitat restoration project has been developed (Scranton Road peninsula).

Figure 30c. Depth contour map showing depth differences between I-90 (at map bottom right) and downstream of State Route 2 (at map top left) on the Cuyahoga River.

Figure 30d. Depth contour map showing depth differences between the area around Columbus Rd. (at map lower right) to the river mouth and the Old Channel (at map left) on the Cuyahoga River.

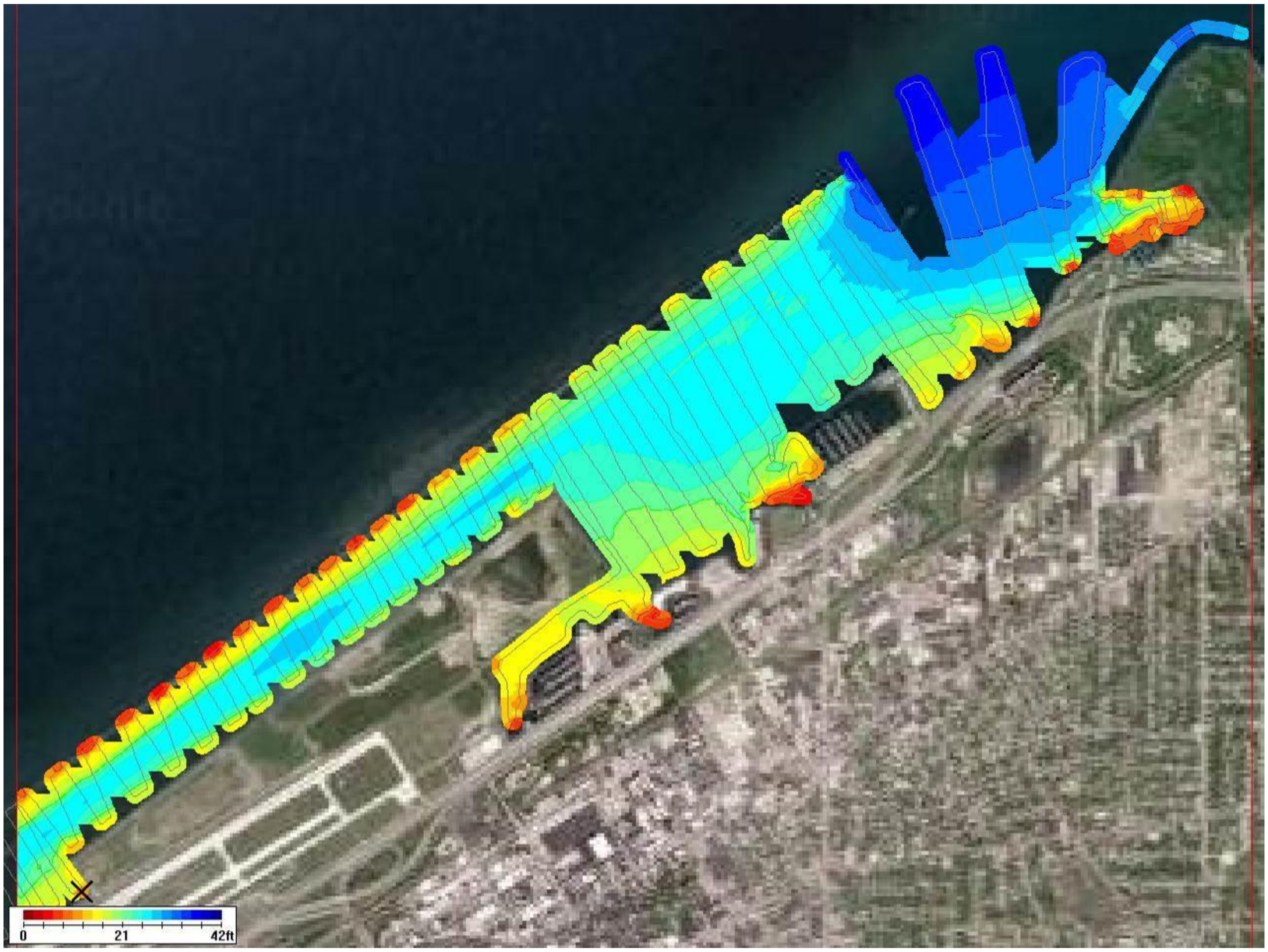


Figure 30e. Depth contour map (in feet) showing depth differences between the area around Cleveland harbor at Burke Lakefront airport (at map lower left) to the east end of the breakwall and Gordon Park (at map upper right).

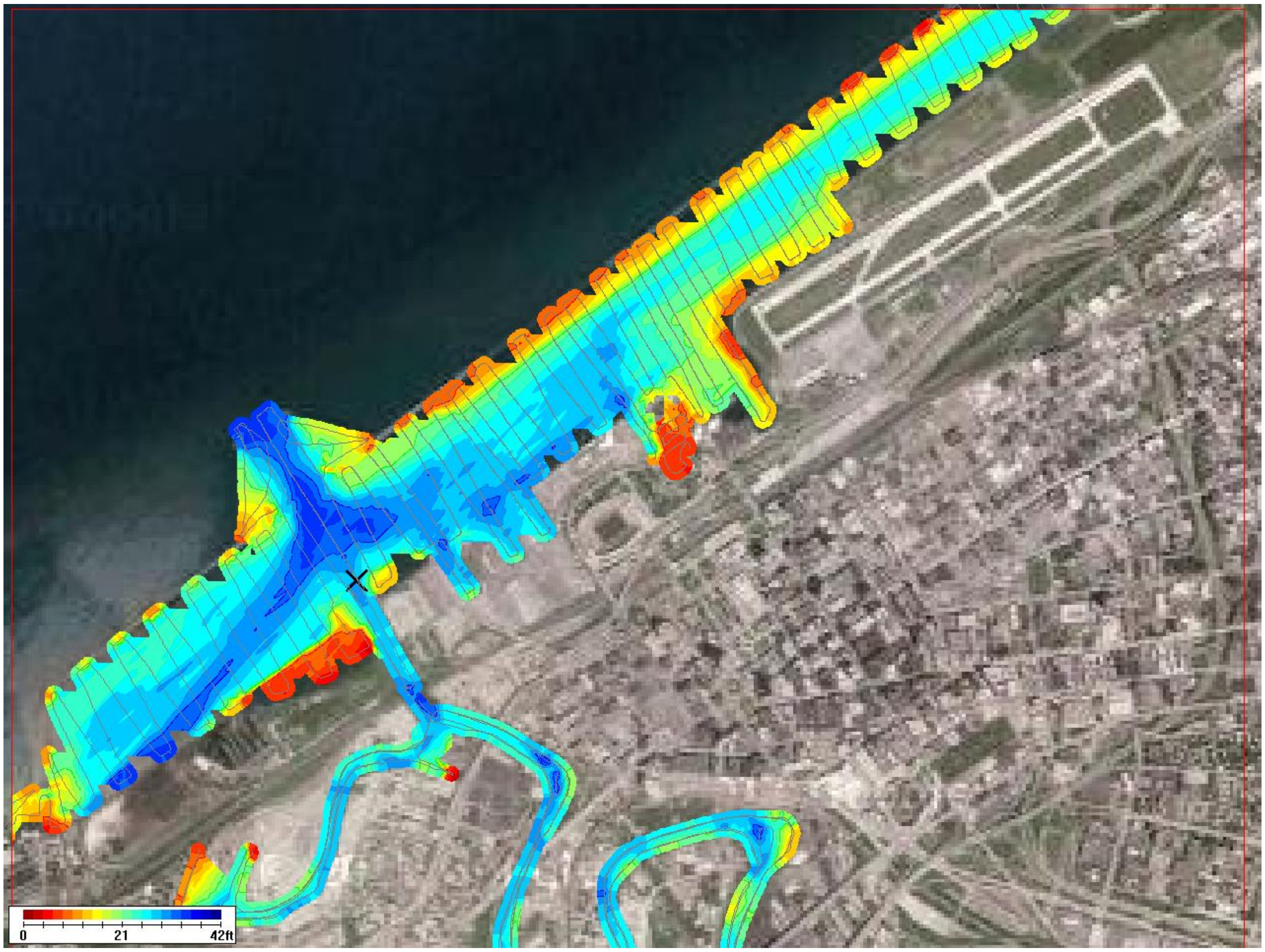


Figure 30f. Depth contour map (in feet) showing depth differences between the area around Cleveland harbor at Burke Lakefront airport (at map upper right left) across the main channel opening to the lake, and to the west end of the breakwall and Edgewater Park (at map lower left).

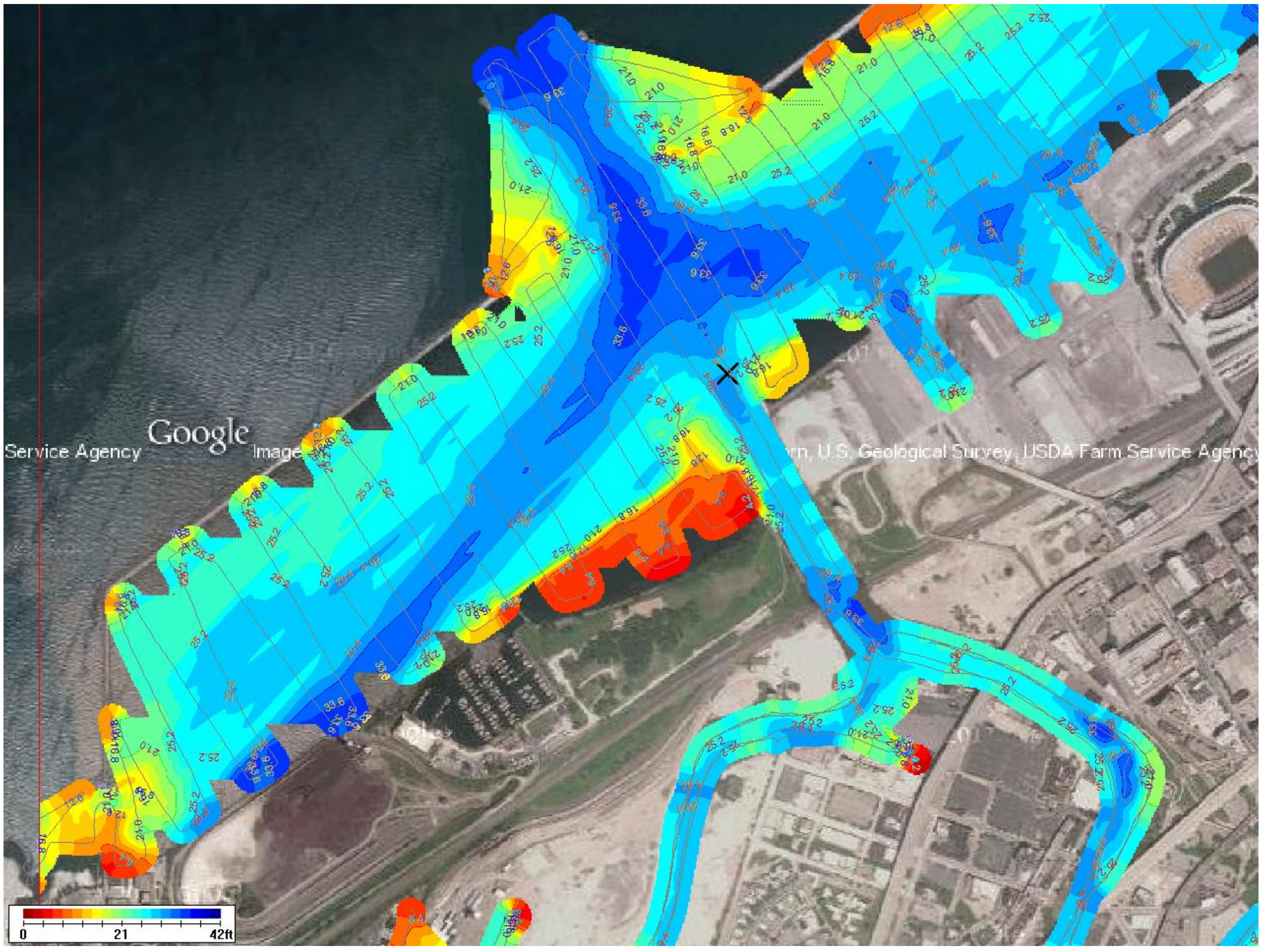


Figure 30g. Depth contour map (in feet) showing closer inspection of the area across the main channel opening to the lake and to the west end of the breakwall and Edgewater Park (at map lower left).

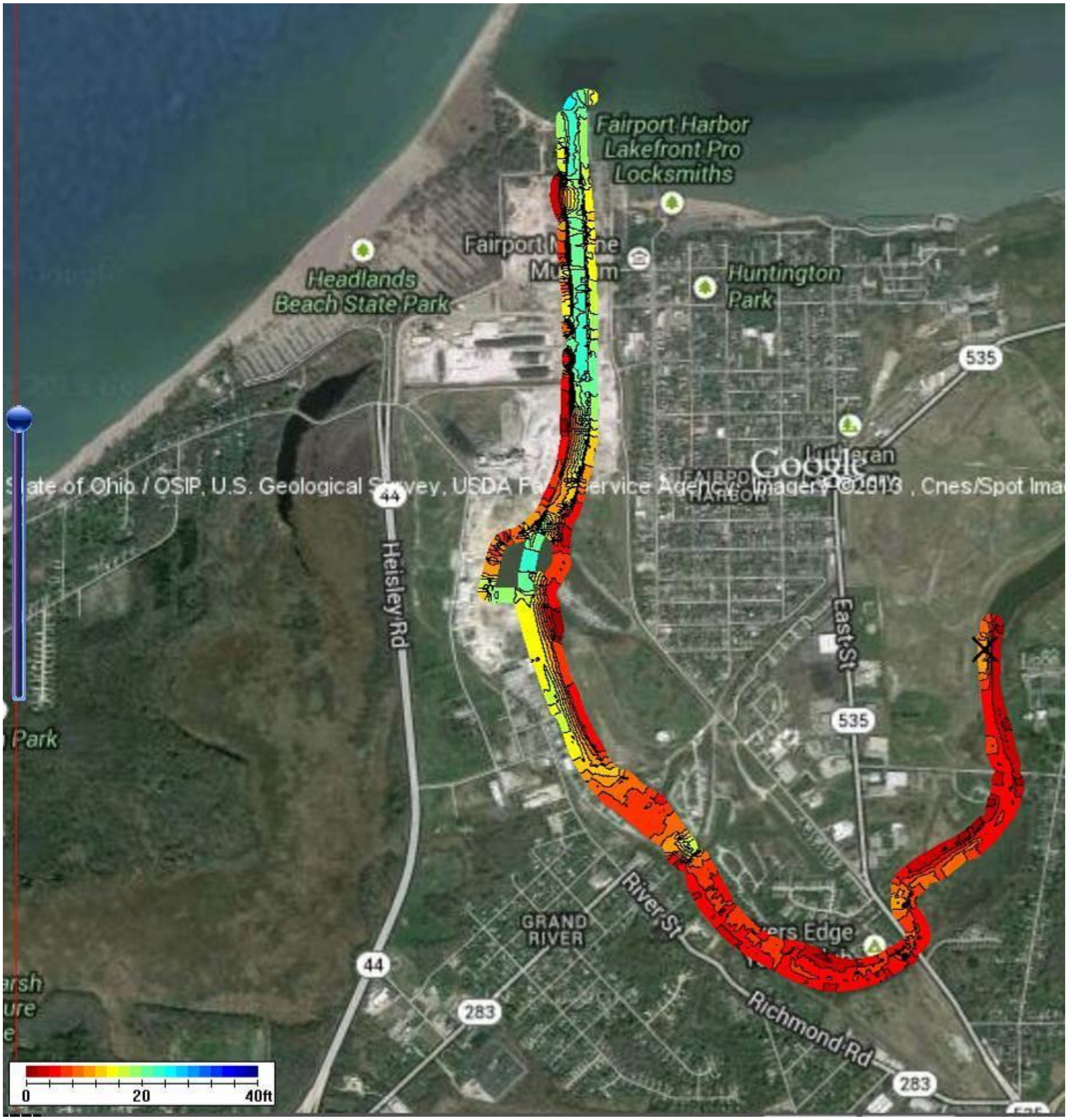


Figure 30h. Depth contour map showing depth differences between the area upstream of the St. Clair bridge (at map lower right) to the river mouth (at map top) on the Grand River.

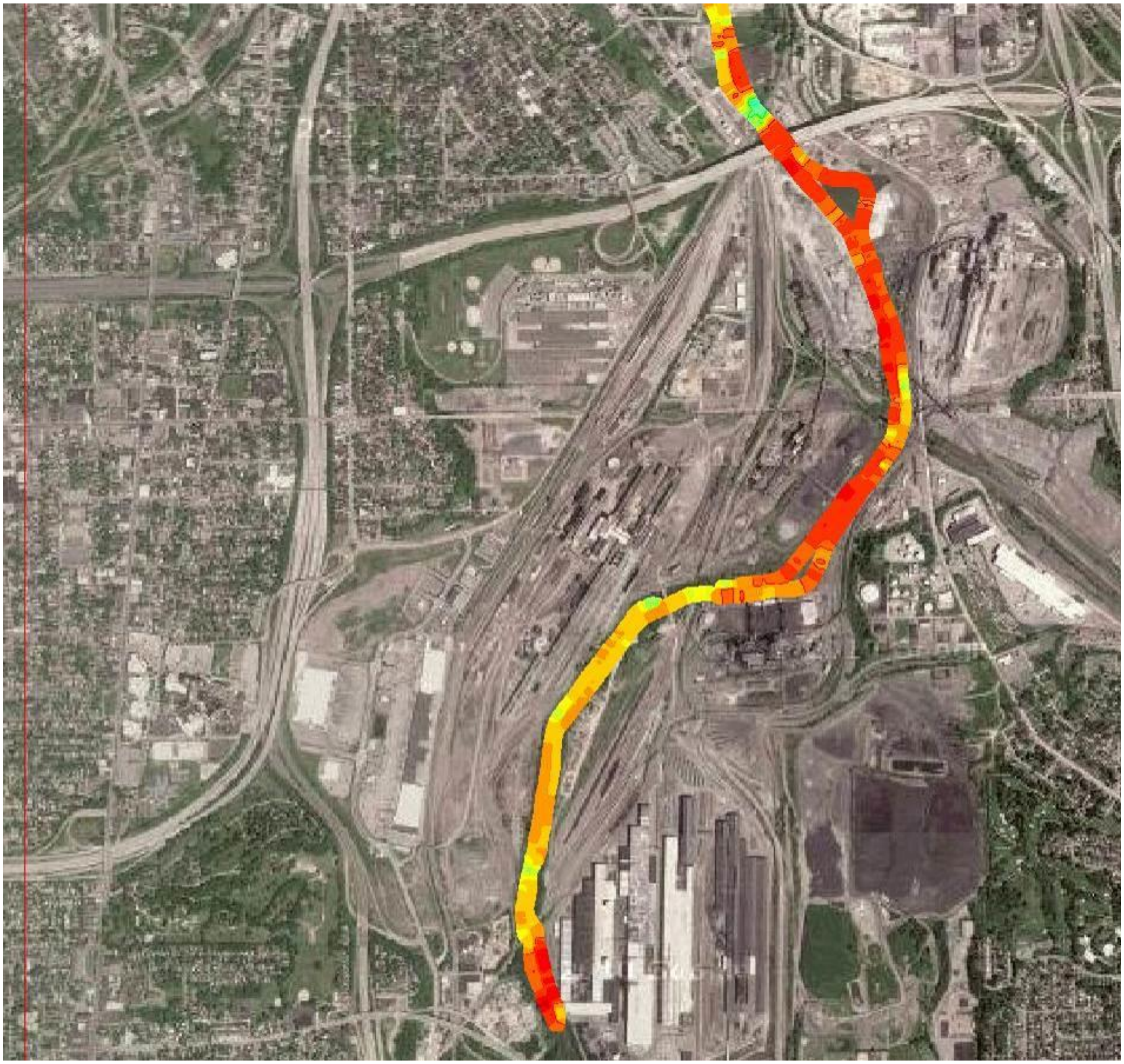


Figure 31a. Bottom type/hardness in the Cuyahoga River from the first riffle (map bottom) to just downstream of I-490 (map top).

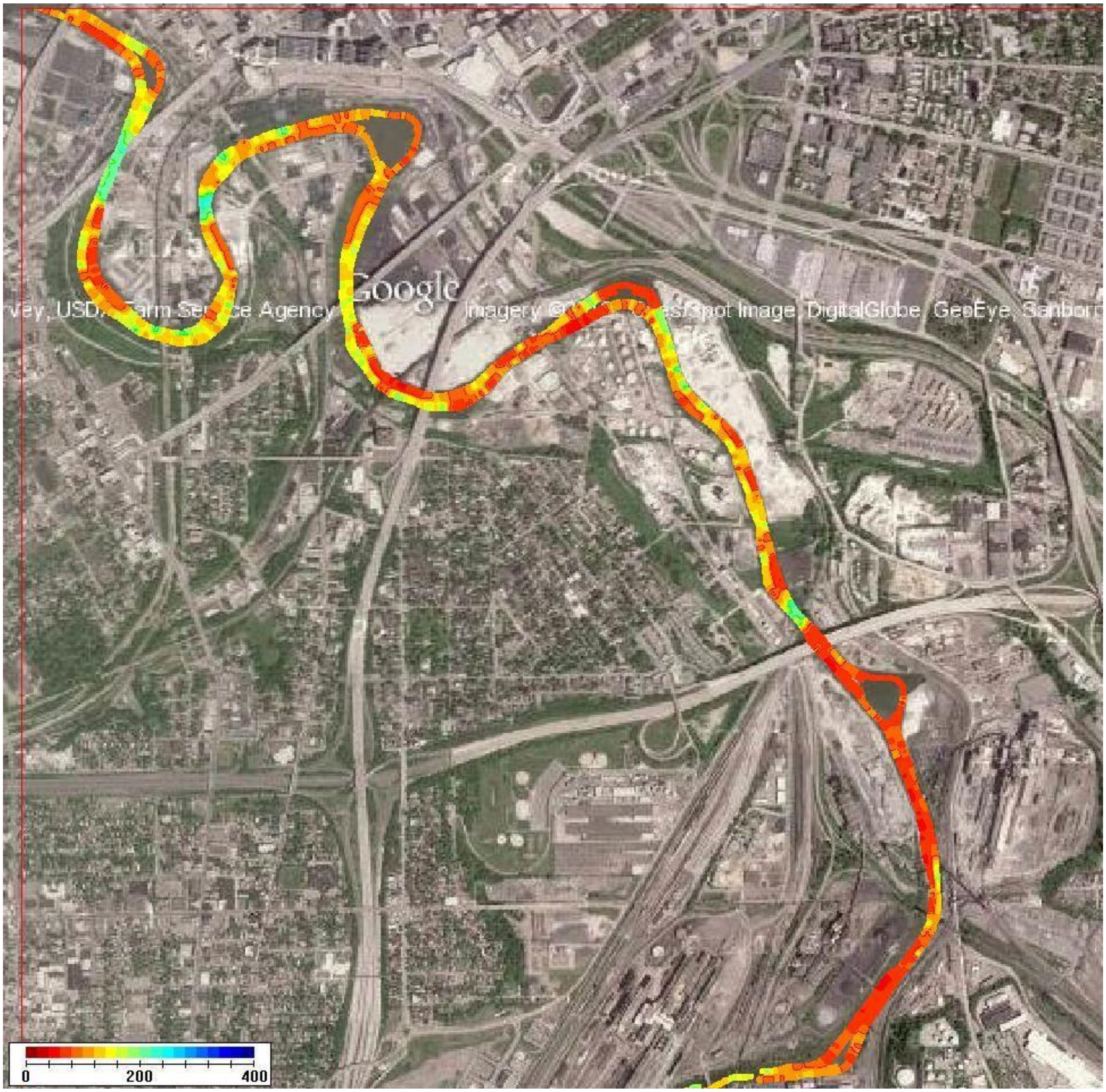


Figure 31b. Bottom type/hardness in the Cuyahoga River from the head of the navigation channel (map bottom) to just downstream of Irishtown Bend and the State Route 2 bridge (map top).

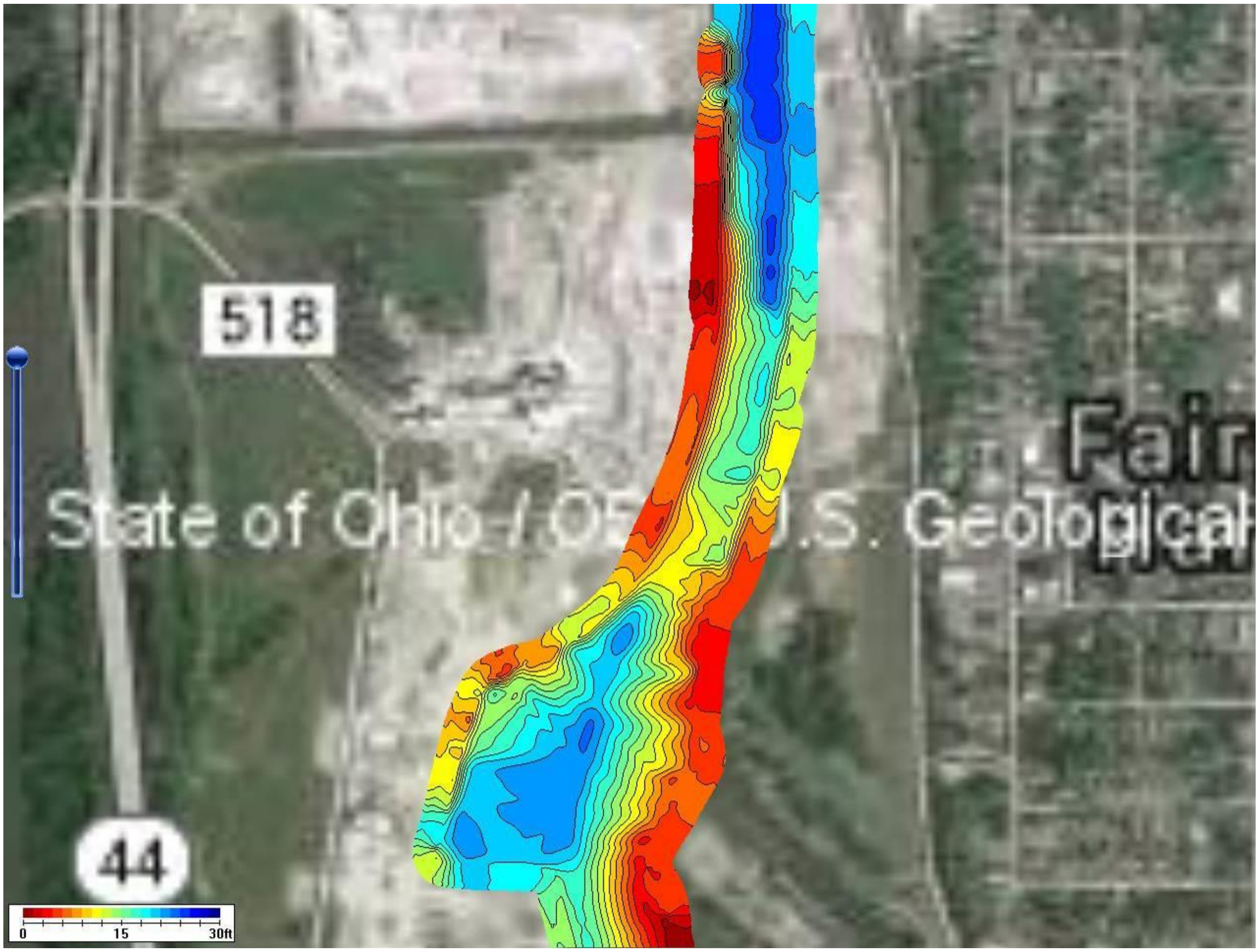


Figure 32. Detailed 1.5-foot depth contour map for the area on Grand River between the end of the turning basin at Grand River Marine (map lower left) and the Morton Salt piles and transfer station (at map top).

Figure 33a. Habitat mapping swath of eastern portion of Cleveland Harbor using Dr.Depth software program from data acquired from Humminbird side scan sonar. Brighter areas are shallower with more coarse-grained materials, dark areas are softer sediments.

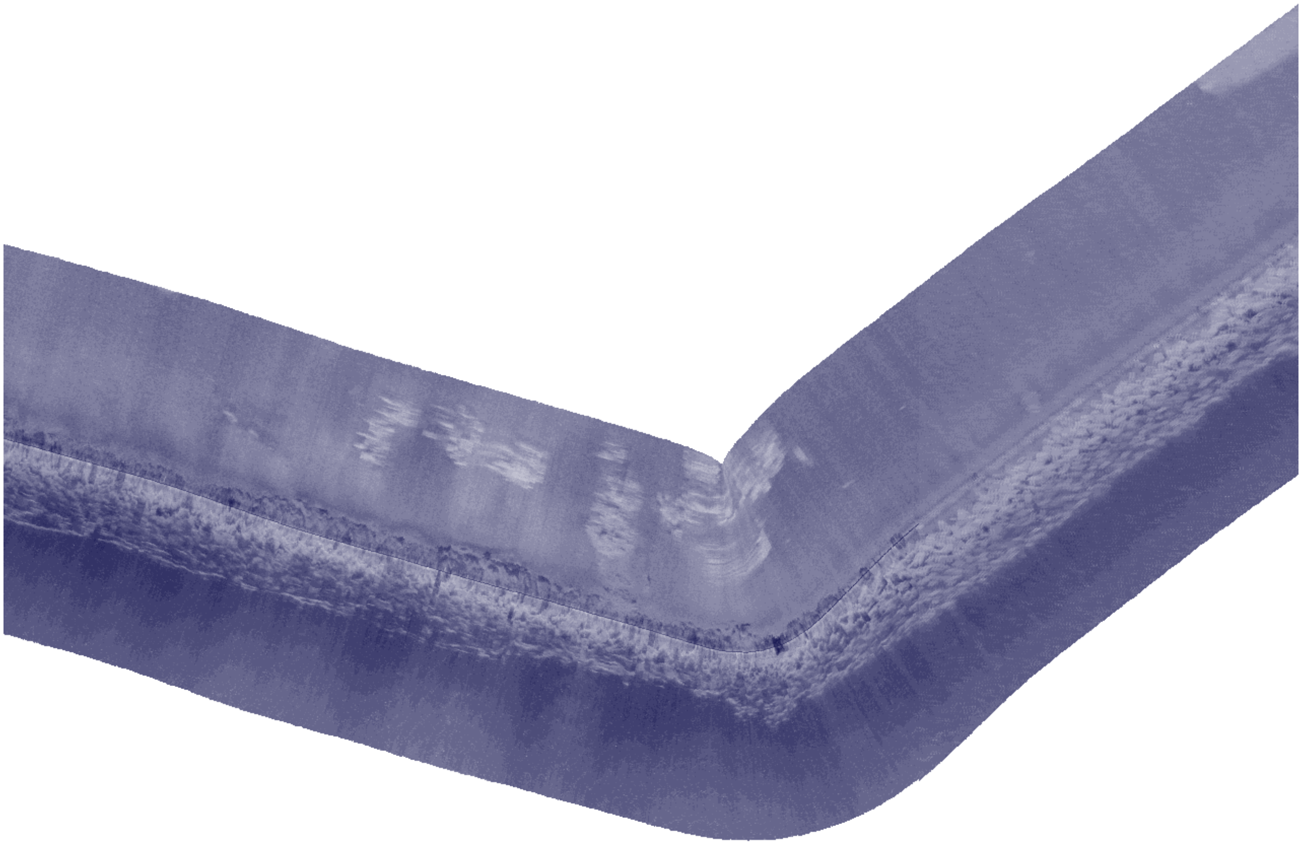


Figure 33b. Habitat hydroacoustic mapping of outer elbow of Cleveland breakwall near the mouth (as seen in the top of Figure 31g) using Humminbird side-scan sonar and Dr. Depth mapping software. The dark area at the bottom represents the breakwall as it breaks over the surface of the water, the middle transition area is the breakwall material as it angles underwater (towards the top of the figure), and the upper areas (nearshore lake area outside of the harbor breakwall) consist of uniform sediment with the exception of a few rock or boulder piles in the turn.

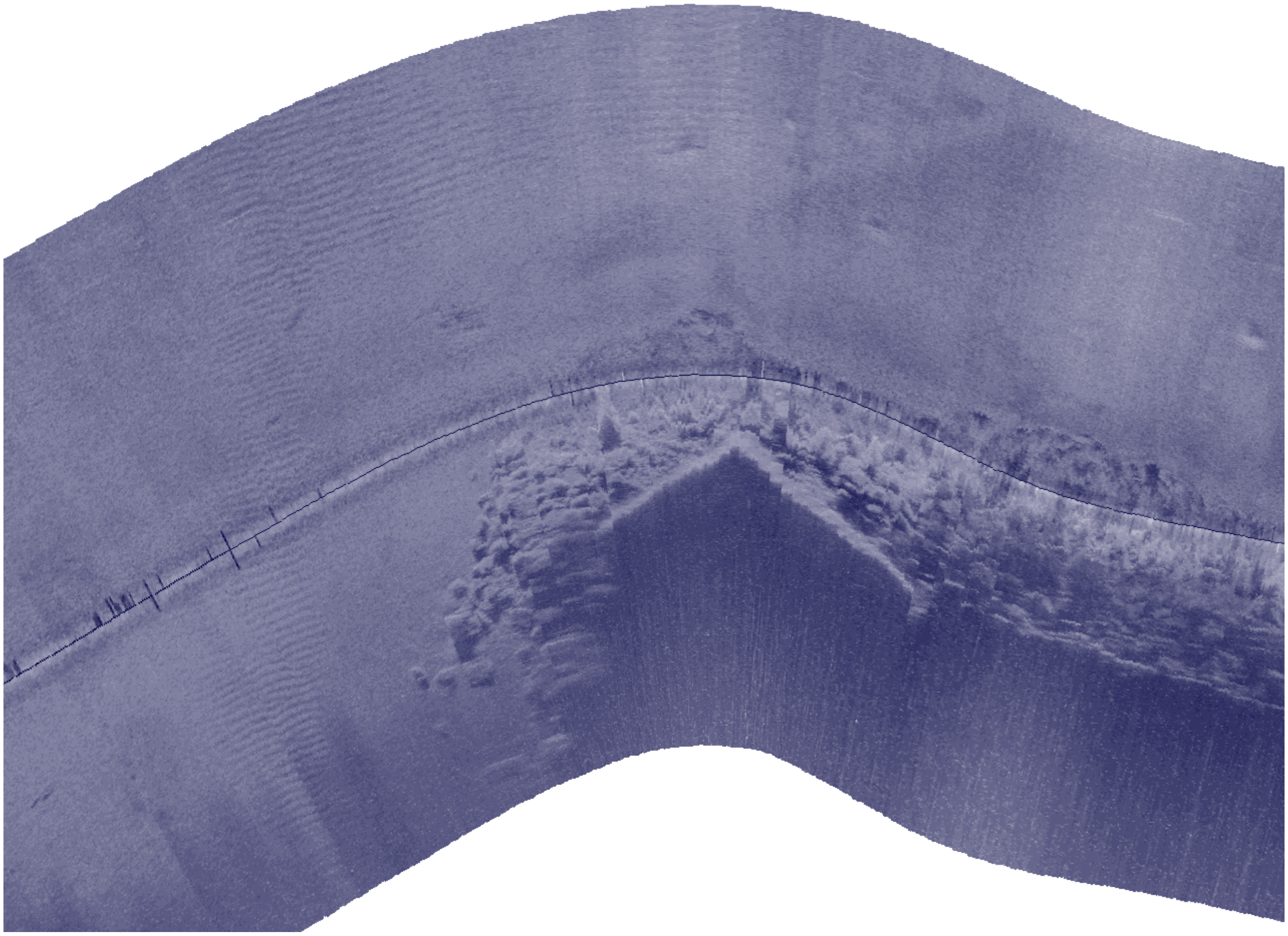


Figure 33c. Habitat hydroacoustic mapping of Cleveland breakwall at the mouth (as seen in the top of Figure 28g) using Humminbird side-scan sonar and Dr. Depth mapping software. The dark area at the bottom right represents the breakwall as it breaks over the surface of the water, the middle transition area is the breakwall material as it angles underwater (towards the top and left of the figure), and the upper areas (nearshore lake area outside of the harbor breakwall) consist of uniform sediment with the exception of a few rocks and wavy sand ridges in the channel and nearshore.

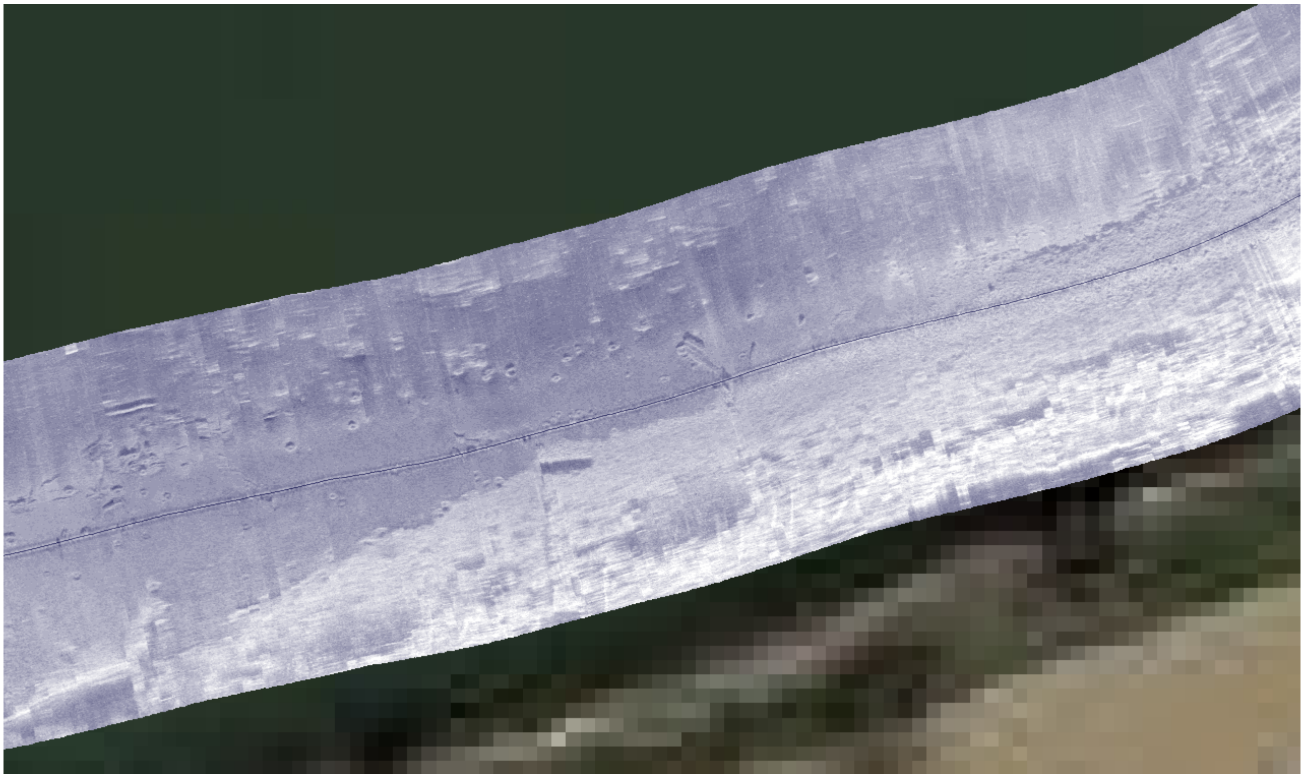


Figure 33d. Habitat hydroacoustic mapping of Wendy Park in Cleveland Harbor showing debris (logs, tires) and shallow nearshore bottom habitat diversity using Humminbird side-scan sonar and Dr. Depth mapping software.

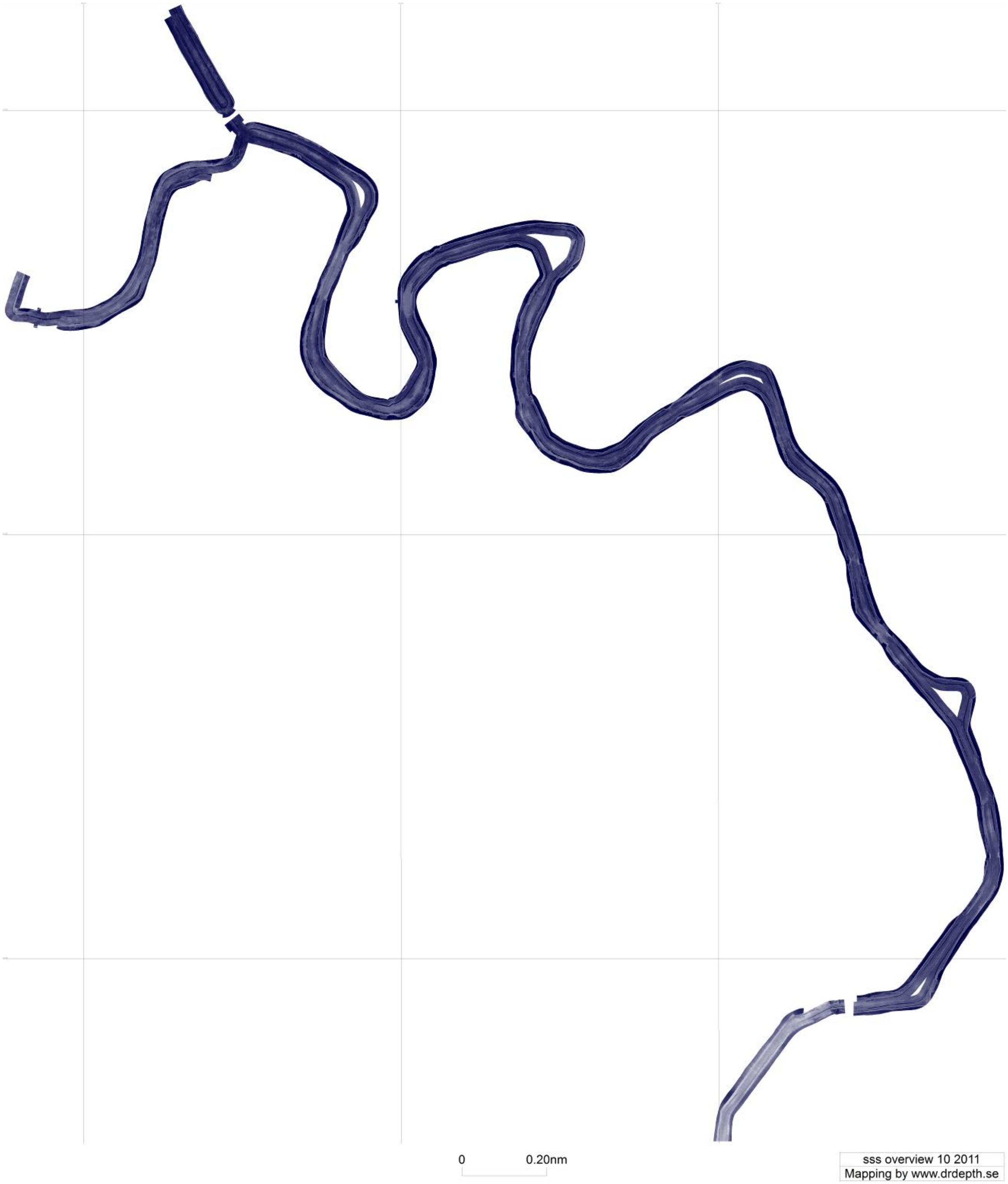


Figure 33e. Side scan habitat sampling overview of Cuyahoga River ship channel and Old Channel (upper left) using Humminbird side-scan sonar and Dr. Depth mapping software.

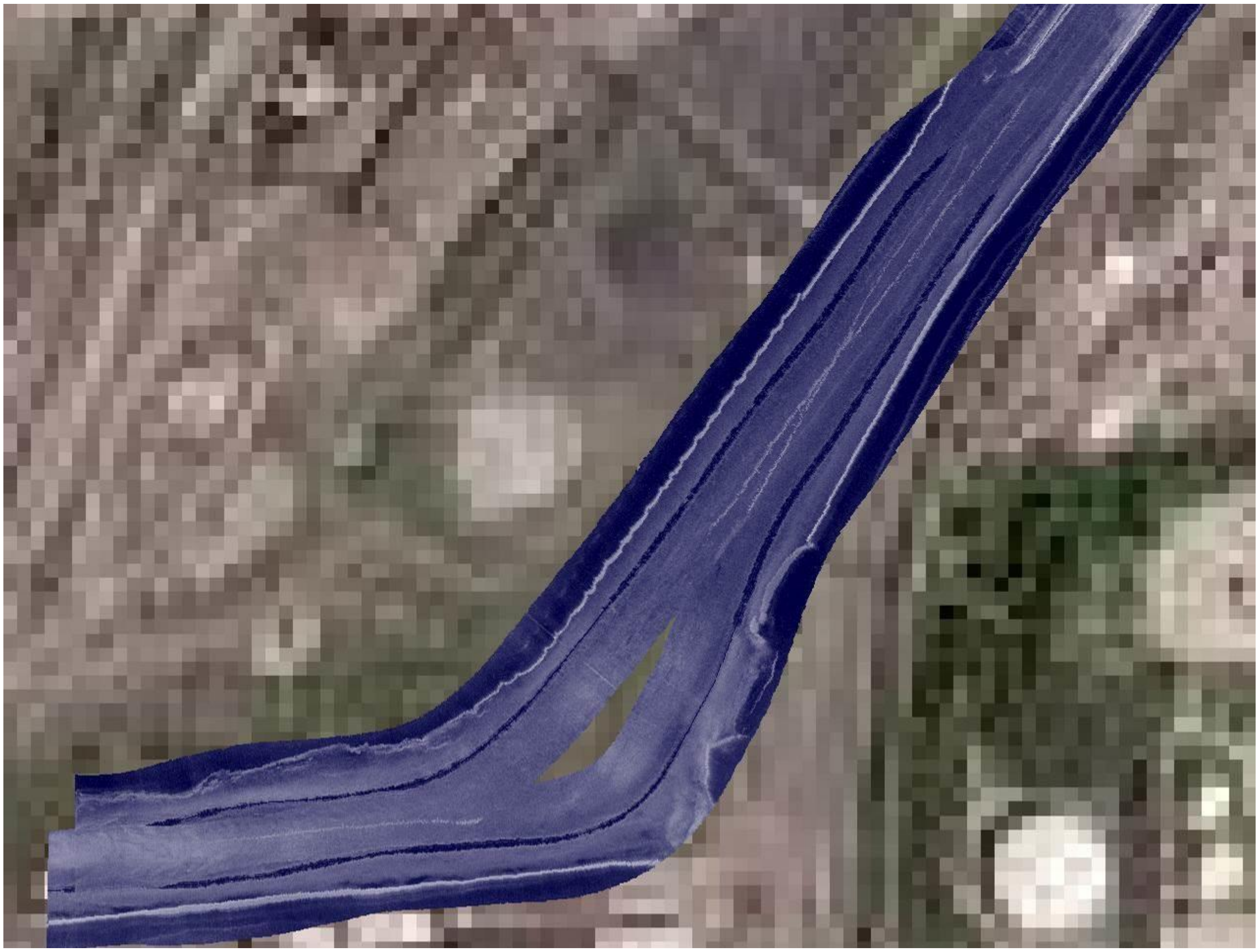


Figure 33f. Side scan habitat sampling of Cuyahoga River ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: head of Navigation Channel at Arcelor-Mittal (going downstream as you go right and up in the figure; north up). The dark blue lines in the river channel represent the (two) center track paths of the boat measuring the water column as it collected side scan data.

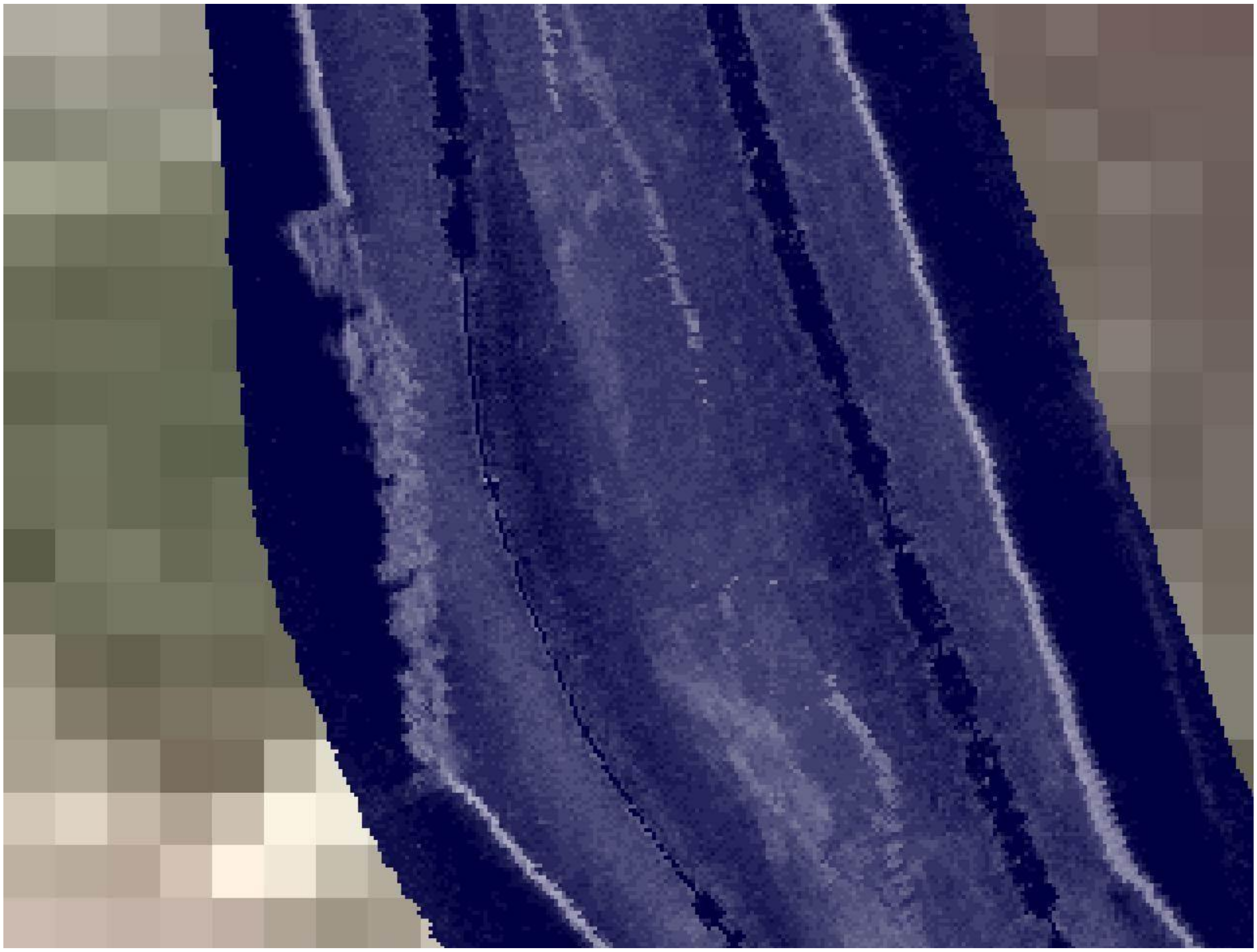


Figure 33g. Side scan habitat sampling of Cuyahoga River ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: station LR-1h, old Green Bulkheads habitat project area on left (going downstream as you go up in the figure; north up). The dark blue lines in the river channel represent the (two) center track paths of the boat measuring the water column as it collected side scan data.

Figure 33h. Side scan habitat sampling of Cuyahoga River ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: above station LR-1h, old Green Bulkheads habitat project area (going downstream as you go up in the figure; north up).

Figure 33i. Side scan habitat sampling of Cuyahoga River ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: the area upstream of I-90 at Marathon Bend and the W 3rd Street bridge (upper left). Mapping reveals uniform bottom depths and deep-water armored shores with the exception of a few bridge abutments (notched areas, bottom right and upper left) and a shallower, diverse rocky area after Marathon Bend but before the 3rd St bridge on the right descending bank above (near the word “image”).

Figure 33j. Side scan habitat sampling of Cuyahoga River ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: I-90 (lower right) downstream to below the Scranton Road peninsula (and old Scaravelli Marina, at upper left), taken in 2011.

Figure 33k. Side scan habitat sampling of Cuyahoga River ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: Old river Channel area,taken in 2011.

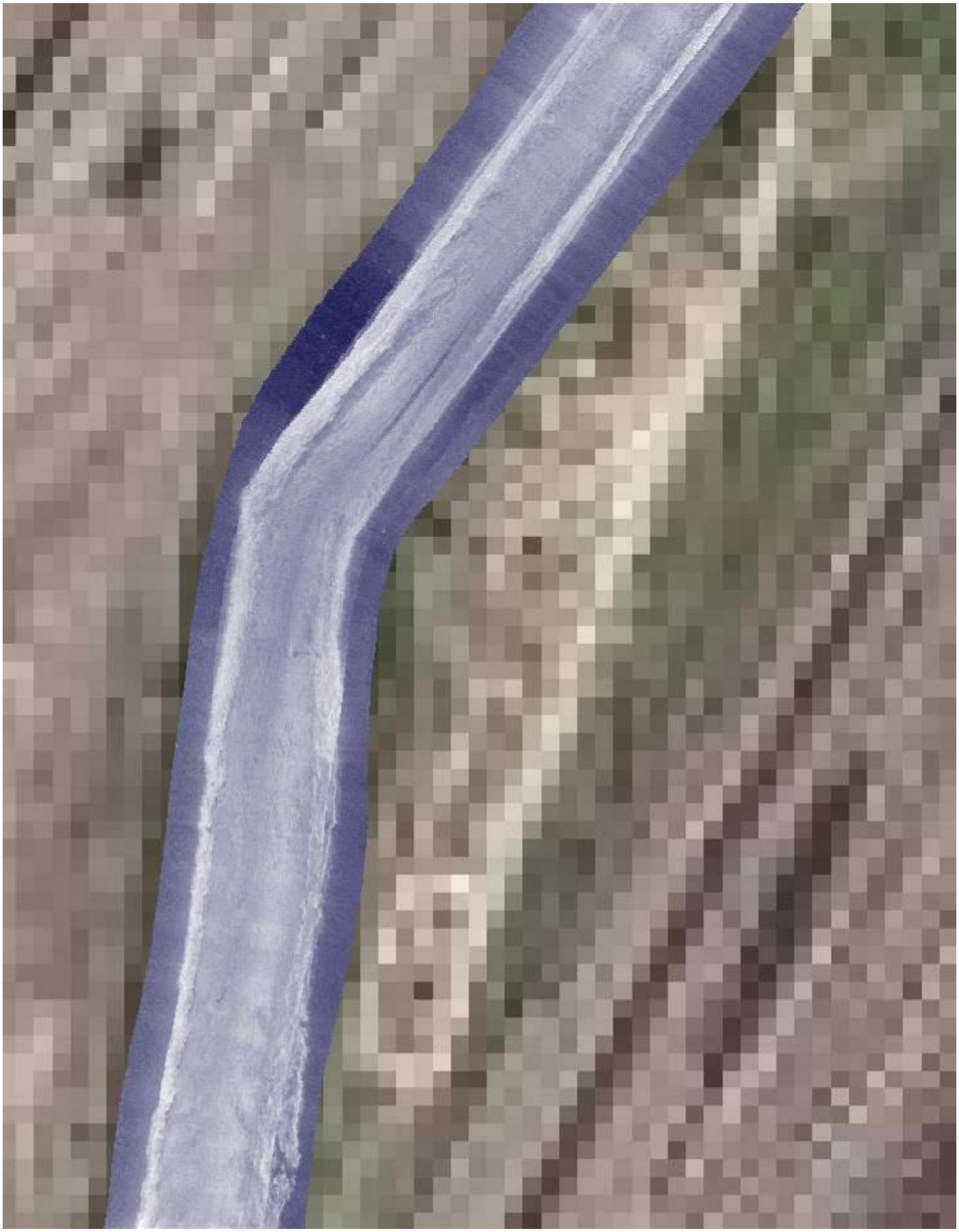


Figure 33l. Side scan habitat sampling of Cuyahoga River above the ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: the concrete channel area immediately above the navigation channel showing more rocky margins and nearshore complexity, but still somewhat uniform depth (8-10 feet).

Figure 33m. Side scan habitat sampling of Cuyahoga River above the ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: the concrete channel area upstream of the previous figure showing more habitat complexity.

Figure 33n. Side scan habitat sampling of Cuyahoga River above the ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: the area below the first riffle to just past the CSX railroad bridge (also seen in the bottom of the previous figure) showing more habitat diversity and shallow water areas.

Figure 33o. Side scan habitat sampling of Grand River above the ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: from the head of the Navigational channel (below) downstream to salt dome loading area (above) showing habitat areas along the margins of the ship channel.

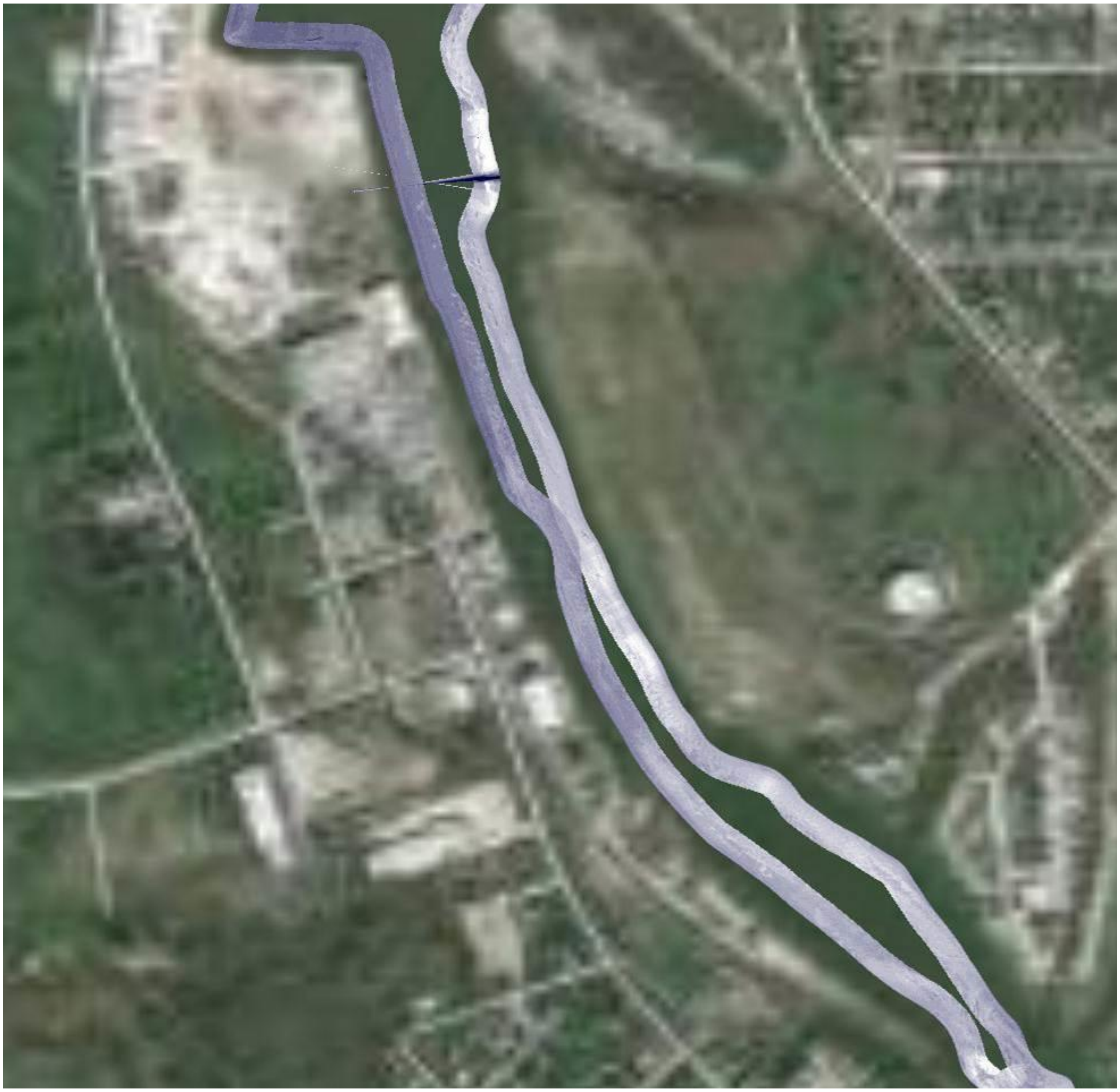


Figure 33p. Side scan habitat sampling of Grand River above the ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: from the old railroad bridge abutments (below) downstream the head of the Navigational channel (above). While this area is dredged intermittently for recreational interests, the margins still show a good amount of habitat diversity and available shallow water.

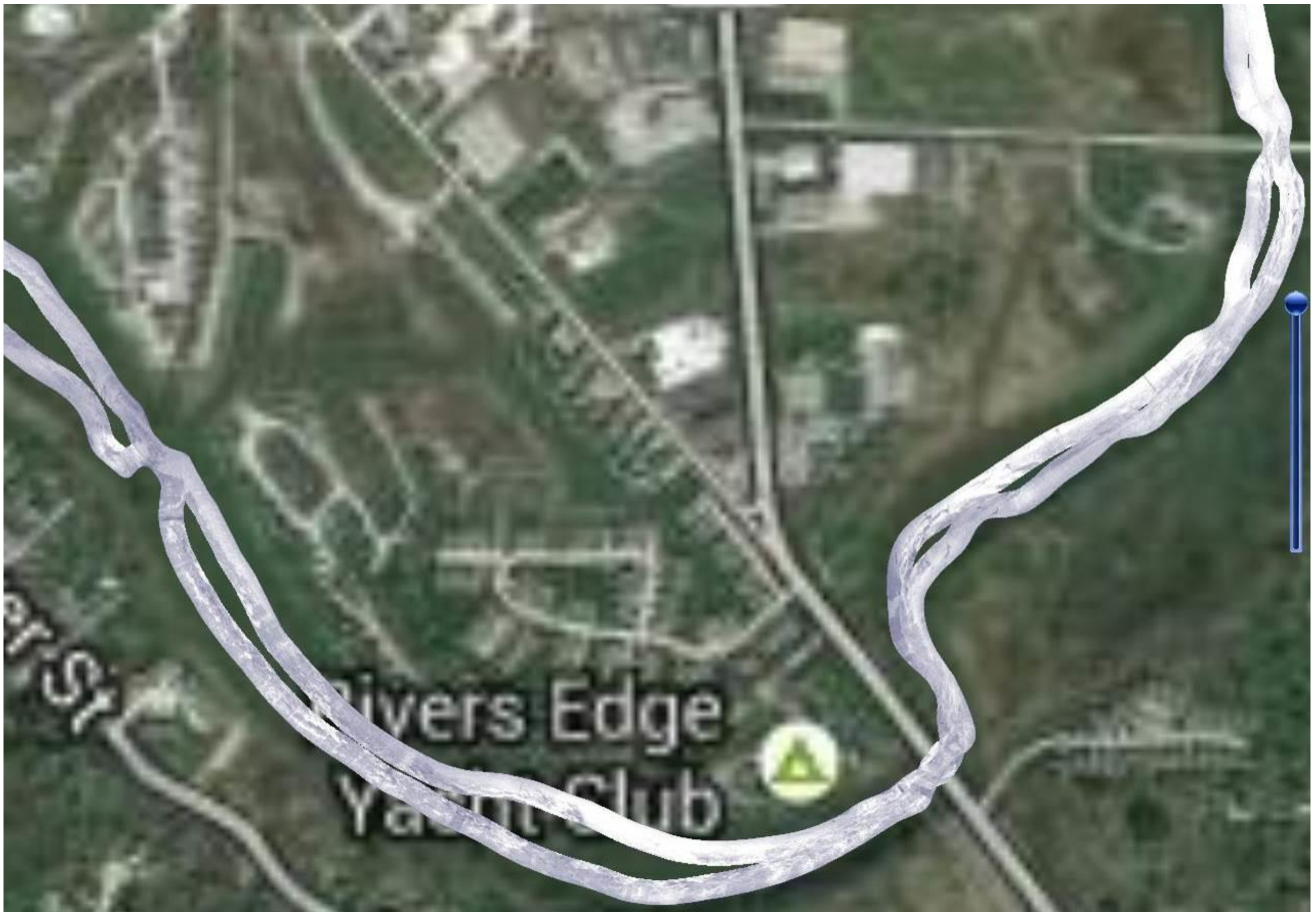
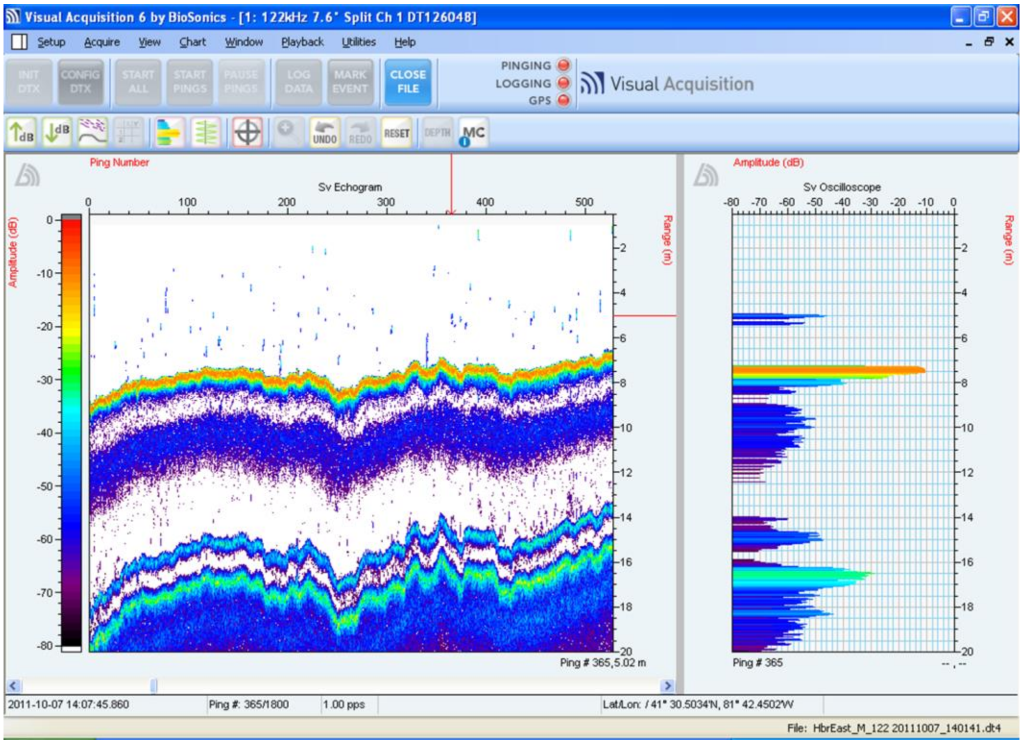


Figure 33q. Side scan habitat sampling of Grand River above the ship channel using Humminbird side-scan sonar and Dr. Depth mapping software: from St Clair bridge (upper right) past State Route 535 bridge, Ram Island, and old railroad bridge abutment (left) showing shallow water habitat and diversity.



Ping # 365,5.02 m

2011-10-07 14:07:45.860

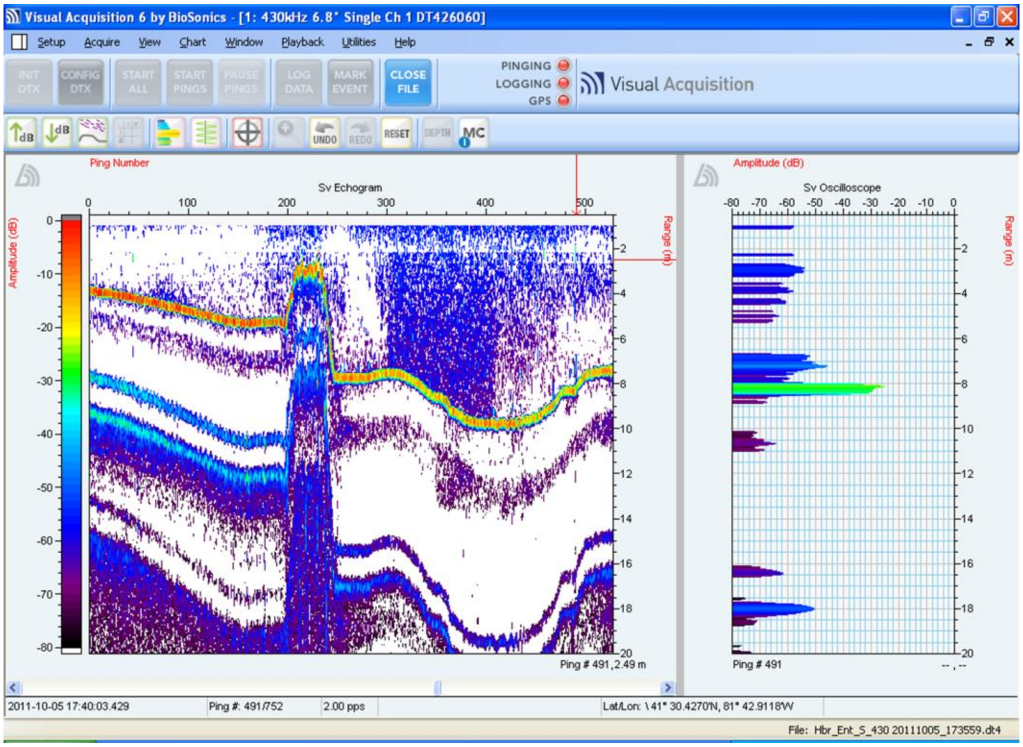
Ping #: 365/1800

1.00 pps

Lat/Lon: / 41° 30.5034'N, 81° 42.4502'W

File: HbrEast_M_122 20111007_140141.dt4

Figure 34a. Illustration of hydroacoustics data from Visual Acquisition software for down-looking echosounder frequencies acquired in a Cleveland Harbor transect.



Ping # 491 ,2.49 m

2011-10-05 17:40:03.429

Ping #: 491/752

2.00 pps

Lat/Lon: \ 41° 30.4270'N, 81° 42.9118'W

File: Hbr_Ent_S_430 20111005_173559.dt4

Figure 34b. Illustration of data from Visual Acquisition software for down-looking BioSonics hydroacoustics data acquired in a Cleveland Harbor transect that transitions into the Cuyahoga River.

Outreach and communications

The Principal Investigator gave multiple presentations describing the scope of work in this project, as well as communicating project goals, products, and outcomes, to local, regional, state and federal stakeholders and members of interested non-governmental groups. QAPP documents, interim reports, and project work plans and data were distributed to other State of Ohio, Cuyahoga County, City of Cleveland, other governmental employees, and interested consultants or parties.

The P.I. participated in activities that informed and advised other rehabilitation projects and in-situ habitat improvement work in the Cuyahoga River shipping channel based on findings from this project. The P.I. has furthered discussion of project mapping techniques using simple side-scan sonar and bottom mapping techniques with the Humminbird system employing programs like “Dr. Depth” and “DeepView” to produce maps and results; however, the buyout and shutting down of Dr. Depth and lack of customer support will limit its future role in analyses, reporting and applications.

ODW employees associated with the project have informed and provided data to habitat project coordinators and interested parties that are involved in restoration work on the Cuyahoga and other rivers in the Lake Erie watershed. We have provided data and assessment results that present baseline data collected during the study period, describing the impairments to the river and aquatic life, in an effort to inform the process of removing Beneficial Use Impairments in the Area of Concern and to complete evaluation of potential improvements in conditions and populations after habitat restoration activities have been implemented. Data presented herein and collected for this project will also be transmitted upon request to researchers and interested parties in order to further the work of ecological restoration and habitat improvements in this and other watersheds.

Discussion

The project data can inform the USEPA and OEPA and Cuyahoga River Restoration (formerly RAP) groups in the process of addressing AOC impairments with the goal of removing the AOC designation. By recalling the 10 beneficial use impairments identified in the Cuyahoga AOC, designated by an asterisk (*) below, and including one for which no data or metric had been established (-):

1. restrictions on fish and wildlife consumption*;
3. degradation of fish and wildlife populations*;
4. fish tumors or other deformities*;
6. degradation of benthos*;
7. restrictions on dredging*;
8. eutrophication or undesirable algae*;
10. beach closings*;
11. degradation of aesthetics*;
12. added costs to agriculture and industry*;
13. degradation of phytoplankton and zooplankton populations (-); and
14. loss of fish and wildlife habitat* ,

it is evident that this project can provide insight as to the progress on remediation of impairments 3, 4, 6, 8, and 14, and assist in determining the status of plankton populations as identified in BUI 13 compared to delisting criteria established by USEPA (2001), OEPA (2014) and the IJC (1991, 2012).

We had no contaminant or bacterial component analyses to this project, so we do not have study results that have direct application to impairments 1, 7, 10 or 12. There were no study measures of aesthetics, so we cannot make any determinations of progress on impairment 11; however, our observations of activities by the Cleveland Port Authority beginning in 2013 to remove debris including plastics, trash and logs in the Cuyahoga ship channel and Cleveland Harbor can be viewed as a positive step in the direction of remediation of BUI 11.

Our study results support the current status quo that fish and wildlife populations (BUI 3 above) in this portion of the Cuyahoga/Cleveland Harbor Area of Concern are still regionally impaired by the old USEPA and IJC standards, but the lower river and harbor fish population metrics now meet or exceed those criteria recently established by Ohio EPA for Limited Resource Waters (LRWs; OEPA 2014). Adult and juvenile fish composition, diversity, and densities; larval sampling success/composition/densities; and fish metrics like IBI (Karr 1981) and MIwb continue to exhibit lower scores in the ship channel and old channel than those observed in neighboring systems that do not have extensive channelized, armored, and slack water conditions. Our (Boat) IBI readings in the 20s and 30s are acceptable for fair to good conditions and actually have similar ranges to IBI metrics offshore in the central basin of Lake Erie (Appendix 4). These study area IBI mean scores meet or exceed the new (OEPA 2014) target thresholds for Limited Resource Waters and Modified Warmwater Habitat for the Erie-Ontario Lake Plain. OEPA (2014) has accounted for the ship channel effects by designating these areas as LRWs, and localized attainment of these new standards for IBI and MIwb is evident; see Appendix 4 and the Cuyahoga AOC website (www.cuyahogaAOC.org).

The fact that fish metric scores improve even more just outside of the study area immediately upstream (by NEORSD evaluations – NEORSD 2012, 2013) or outside of the ship channel as near as the harbor breakwall (by ODW - this project- and trawl and gillnet samples – ODW 2012, 2013, 2014) further illustrate the limited scope of any impairment (and reduction in available fish habitat, which will be discussed later in BUI 14 analysis) in the ship channel. By establishment of his lower threshold for the ship channel LRWs, in an area that will remain a dredged ship channel for the foreseeable future, a fairer assessment of expected progress and potential under these severely altered conditions can be made. Nevertheless, these fish metric scores for river and harbor still reach and/or exceed the attainment of designated LRWs and MWHs (compared to OEPA 2014) for the Erie/Ontario Lake Plain.

There are other evaluations of fish populations besides the IBI and MIwb metrics that can serve as statements of fish population status and health. There are known seasonality shifts and migratory swings in abundance and biomass that can lead to very different metric scores. The presence of sensitive or rare fish species and species of sport and commercial importance to the river, nearshore and Lake Erie fisheries are also worth discussing.

In September 2015, NEORSD personnel collected juvenile Walleye, Yellow Perch, White Bass, and White Perch (lake migratory species) in Cuyahoga River electrofishing samples upstream of the ship channel and immediately above our first riffle site (Seth Hothem and John Rhoades, NEORSD, pers. comm.). It has not been determined if these fish originated in the Cuyahoga River or migrated up river for feeding and refuge from Cleveland harbor and Lake Erie. Annual migrations of lake fish species during the fall through spring have been noted by our project sampling efforts and others. Fish use of the lower river and harbor as a travel corridor between the mid-river, harbor and lake is a potentially positive sign of fish population re-establishment and recovery.

Also noteworthy was the presence of intolerant fish species and fish species that are of interest to sport and commercial fish interests in the lower river, ship channel, old channel and harbor. Populations of resident sport fish appear to be rebounding, with juvenile centrarchids (bass and sunfish) densities increasing to levels observed in other nearshore or dredged areas and harbors (these are also designated as LRWs or Modified Warmwater Habitats [MWHs]; OEPA 2014). The presence of adult Walleye, Smallmouth Bass, White Bass, and Northern Pike in the harbor sampling efforts, and the catches of Steelhead Trout in the spring will support sport fishery interests throughout the seasons. Intolerant fish species such as Spotted Sucker, Silver Redhorse, Logperch, Longnose Gar, and Brook Silverside were also observed in our electrofishing samples, further exemplifying that some stages of recovery in fish populations are underway in the ship channel and harbor.

Our recording of fish tumors and deformities in electrofishing samples can provide some limited insight on progress against the fish tumor impairment, BUI 4. Our observed percentage of DELTs, at 3.1% across all years of sampling for all fish measured (Appendix 4), is essentially at the target level of 3% (IJC 1991, 2012, OEPA 2014). Annual estimates of DELTs ranged from 2.5-3.6%. Our DELT estimating procedure is somewhat conservative (giving higher percentages than actual) in that not all fish that we observed in electrofishing were brought to the boat tank and measured. Most of the small fish that were field counted were juvenile emerald shiners and gizzard shad, two species with a low occurrence of DELTs. At no sites across our four study years did the incidence of DELTs exceed twice the target rate of 3% - which is the applicable value to determine the whole assessment unit in non-attainment. With this low of a recorded percentage on our fish observations, and concurrence by other agency studies in the AOC, further detailed studies by OEPA in the AOC should be undertaken for concurrence with our work and that of NEORSD in 2012 and 2013, as removal of this BUI may be warranted.

With BUI 4, the OEPA has also determined that the incidence rate of Brown Bullhead liver tumors should not exceed 5% occurrence. We did not sample enough Brown Bullheads to be able to make an adequate determination of this part of the BUI 4 metric; nor did we sacrifice fish to examine liver status. Our limited electrofishing surveys captured 12 Brown Bullhead across the four years of the field studies. Only 1 (8%) exhibited any external DELTs. Further targeted studies are needed to address the status of the population and the attainment of this segment of BUI 4.

Further delineation of this BUI may also be needed. It appeared that many of those fish exhibiting DELTs were older fish sampled in areas of the lower Cuyahoga River and Old Channel – areas where legacy contaminants may still be an issue. This persistence of older, affected fish (exhibiting impacts long ago becoming established in the fish) may be confounding an accurate measurement for this BUI metric.

The Great Lakes Fishery Commission’s Sea Lamprey Control Program personnel from the US Fish and Wildlife Service and Department of Fisheries and Oceans Canada assess progress against Sea Lamprey population targets by examining lamprey wounding rates on Lake Trout for specific sizes and age ranges (Sullivan and Adair 2014, [LEC] Cold Water Task Group 2015). By employing that method of a specific species and size range, they can ascertain progress versus targets as new recruits are coming into the adult population, and the older fish that have old wounds do not confound the current dataset.

It is suggested that a similar method can be employed that looks at DELTs and liver tumors. By targeting a specific size or age of fish, it can be determined that recent events or exposures may have resulted in these impairments. We cannot assume that DELTs or liver tumors cause 100% annual (or other short time period of interest) fish mortality. Inflictions from old, previous exposures in significantly larger, older fish could be discounted in the assessment or calculations of this metric, allowing better evaluation of progress over time.

The evaluation of BUI 6 – degradation of benthos – employs a similar tiered approach based on site location and the designated use in that part of the watershed (OEPA 2014). For the Limited Resource Waters found in Cleveland Harbor and the lower Cuyahoga River, that means the restoration targets for the Invertebrate Community Index are 4 in the riverine areas and 12 in the lacustrine areas. Warmwater habitat lacustuary ICI scores (L-ICI) are to meet or exceed a score of 34. The riverine areas in the Modified Warmwater Habitats must achieve an ICI score of 18 (OEPA 2014).

Our data collected in this study will not have a direct impact on attainment of this BUI, as OEPA ICI data is used solely to inform progress in this metric. Our study data collected lacks the statistical rigor to be able to make a statement on progress on this metric. We sampled relatively few areas in a more qualitative manner to complement NEORSD annual benthic sampling procedures - and not duplicate or possibly affect their areal results for their regulatory sampling. Many of their benthic sampling stations were adjacent to our water quality and plankton sampling stations (LR0/River Mile [RM] 7.0; LR1/RM 5.9; LR2/RM 2.75; LR3/RM 0.2), so their results can be viewed as applicable for the study area and for 2011-2014 timeframe (Appendix 4, NEORSD 2012, 2013, 2014, 2015). These results show that the NEORSD L-ICI scores meet or exceed the OEPA criteria for benthic community standards. The lowest value recorded across the four years was 18, which was sufficient for attainment in riverine Modified Warmwater Habitats, but not in Lacustuary habitat. This is in spite of the OEPA (2014) caution that this BUI standard will not be evaluated in waters that are routinely dredged as “it is unrealistic for a healthy benthos community to be restored under these conditions.” There have also been communications (Scott Winkler, OEPA, pers. comm.) that there are errors in the procedures and calculations affecting the L-ICI benthic scores that need to be addressed.

While much of the Cuyahoga AOC in the ship channel is dredged on an annual basis, evaluations in un-dredged or infrequently dredged areas can be targeted to monitor progress. In this light, ICI scores at LR0, LR2 (Scranton habitat improvement area), and those obtained by NEORSD above the study area are still applicable to monitor improvements in this metric.

Further annual work should also be continued to address and improve sediment contaminant issues that are also a part of this BUI standard. The lower segment of the Cuyahoga ship channel from I-490 downstream to the mouth continues to have persistent legacy chemical issues, resulting in dredge sediments being disposed into the Cleveland Harbor Confined Disposal Facilities (CDFs; OEPA 1999, 2010). As with the fish population metric (BUI 3) and fish tumor metric (BUI 4), the benthic community metric (BUI 6) should be re-evaluated by OEPA (and should include NEORSD annual assessments) to address potential BUI removal in the middle river, lower river and harbor, based on revised OEPA 2014 standards and recommendations for attainment. As we report on and continue to monitor abiotic conditions (BUI 8), we would expect an improvement in these parameters (DO, nutrients) would have an effect on benthic populations as well.

Our study collected sufficient amounts of abiotic and plankton data (including nuisance blue green algae) to make a statement about progress against BUI 8; impaired conditions due to nutrient enrichment and eutrophication, undesirable algae, and anoxic to critically-low dissolved oxygen (DO) in the water column. Nutrient levels have to be low enough as to not proliferate nuisance algal blooms from anthropogenic (human-induced) sources within the AOC. Total phosphorus (TP) sample values above 50 ug/l and chlorophyll *a* (chl *a*) values above 10 ug/l are considered to be contributory to hyper-eutrophic conditions and excessive algal blooms in Lake Erie (Leach et al. 1977 and Ryan et al. 2003). The Lake Erie Fish Community Goals and Objectives, as promoted by the Great Lakes Fishery Commission's Lake Erie Committee, strive for mesotrophic conditions of 9-18 ug/l of TP and chl *a* values in the range of 2.5-5 ug/l to promote ideal conditions for percids (Walleye and Yellow Perch) in the western and central basins of the lake.

Our study data support the notion that the Cuyahoga River watershed is a contributor to highly eutrophic conditions in the lower river, Cleveland harbor, and nearshore Lake Erie, based on our total phosphorus (TP), soluble reactive phosphorus (SRP), and chlorophyll *a* (chl *a*) results. Also supporting this finding are the nuisance algae densities recorded in our plankton samples in the lower river and harbor. Our TP, SRP and chl *a* values recorded a great deal of variation between the areas above the ship channel (LR0) and outside the breakwall (OB1 and OB2) compared to the ship channel and old channel stations (LR1, LR2, OC1 and OC2 - see Figures 18 and 19 and Appendix 3). The lake stations and naturalized river channel station above the ship channel do have episodes or pulses of nutrients that push readings into more eutrophic conditions, but they are transitory in nature as nutrients move through the system or are used by algae. The harbor, lower river, and old channel sections frequently had values of TP and chl *a* that were well above the defined hyper-eutrophic thresholds. The dredged channels may be acting as a nutrient sink reservoir that can then release high-level pulses of nutrients when extreme high water events occur. Mixing and agitation vertically in the water column and horizontally through the system can also occur from ship traffic in the river.

These levels of nutrient-rich water can give rise to nuisance harmful algae blooms (HAB) like *Microcystis*, as observed in our plankton samples (see previous results and discussion of BUI 13, below). These harmful algal blooms were found in lower river, harbor, and nearshore Lake Erie. The one mitigating factor that may keep the lower river and harbor from having perpetual HAB issues is the persistent high turbidity that exists in these areas. The resulting low water clarity may keep local HAB blooms in check as light transmission is quickly filtered out in the top of the water column, thereby limiting the productivity zone.

Comparing the nutrient inputs of the Cuyahoga River on a regional scale, we can compare the TP concentrations to other major river watersheds that flow into Lake Erie. Our data, combined with Heidelberg's National Center for Water Quality Research (NCWQR) data, can allow comparisons with Cuyahoga, Sandusky and Maumee river TP readings. When comparing data for the period of March 1 to October 31 during the years 2011-2014, the Cuyahoga station recorded lower mean TP values than the Sandusky station in all four years and lower TP values than the Maumee station in two of the four years (Table 11). While the annual statistical variability in TP makes significance difficult to determine, further analysis of time-series data and synchrony of TP values with water levels is warranted. Regardless, the Cuyahoga can be viewed as a moderate to substantial contributor of phosphorus to the central basin of Lake Erie.

Table 11. Comparisons of mean±stdev TP readings (mg/l) at Cuyahoga, Sandusky and Maumee stations from March 1-October 1, 2011-2014, as reported by the Heidelberg NCWQR.

Station	Year	2011	2012	2013	2014
Cuyahoga		0.197±0.217	0.183±0.162	0.207±0.175	0.217±0.282
Sandusky		0.343±0.229	0.221±0.244	0.255±0.193	0.253±0.219
Maumee		0.278±0.184	0.181±0.157	0.247±0.153	0.216±0.130

Impairments from reduced dissolved oxygen levels in the Cuyahoga AOC have long been documented. Early studies in the Cuyahoga RAP and AOC remediation process pointed to low DO and anoxic conditions that began at many sample sites as early as May and persisted until the fall (OEPA 1999). It has long been stated that the stagnant conditions of the reservoir-like nature of the dredged ship channel act like a nutrient sink and give rise to increased oxygen demand, making these poor DO conditions persist.

The newer OEPA guidelines (2014) establish DO targets in ship channels, LRWs and other designated use categories. Those DO criteria of interest for comparison in the study area include: minima of 1.5 mg/l in the designated ship channel, 2.0 mg/l in Limited Resource Waters, and 2.5* mg/l in modified warmwater habitat (*as established in Ohio Administrative Code). Dissolved oxygen 24-hour averages are also established for LRWs at 3.0 mg/l (OEPA 2014). In review of our DO data collected at sample stations during 2011-2014, there was only one occurrence on the Cuyahoga where surface water DO readings were below 1.5 mg/l – and that was in the Old Channel (OC2) in 2013 (see Figure 11 in Results). Bottom DO readings at sample stations did go below 1.5 mg/l more frequently during that time period; 8 times in the lower Cuyahoga stations, LR1 & LR2; 6 times in the Old Channel stations, OC1 & OC2; and 4 times in the Cleveland Harbor stations, H1 & H2 (see Figure 11). There were no occurrences of very low DO at stations OB1, OB2 or LR0.

Also of note was the relatively good readings of dissolved oxygen and % DO saturation recorded from the data sondes during 2014 (Figure 12 in Results). For the most part, DO values observed during this study meet or exceed those minima values set for the designated ship channel and the limited resource waters. DO values above the ship channel at station LR0 never were lower than 6.0 mg/l, by station or data sonde readings, far exceeding the minima set for modified warm water habitat. The data sonde readings at the other stations (LR1-LR3) would meet the 24-hr averages set for LRWs; LR1 and LR2 may even meet modified warmwater habitat, by DO minima values recorded, but more data is required to be sure that 2014 is a "typical" river year. It was noted that DO values did sag (sequentially) from the data sonde location above the ship channel at LR0 to stations in the ship channel; LR1, LR2, and LR3. Again, the stagnant reservoir effect of the ship channel, coupled with oxygen demand in the ship channel, affect DO quality as you go downstream in the ship channel and into the harbor. Data sonde DO readings confirm that progress has been made to meet or exceed the BUI metric standards, but more years of data are needed to confirm these improvements. The DO improvements are becoming evident throughout the channel, but the effects are most noteworthy farther upstream from the mouth.

Pursuant to the current BUI in the Cuyahoga ship channel and OAC (Ohio Administrative Code) 3745-1-26, the OEPA (2014) document states:

> "Specifically for the Cuyahoga River, exceptions for the dissolved oxygen criteria are included in OAC 3745-1-26 for the LRW waters identified as the Cuyahoga river ship channel (river mile 5.6 @ the Newburgh and South Shore RR Bridge to the Cleveland harbor portion of Lake Erie). According to the rule, "the physical habitat of the channel and the prevailing background dissolved oxygen regime are insufficient to support any resemblance of the warmwater habitat aquatic life use designation. A use attainability analysis has been conducted and indicated the extant fauna is substantially degraded and the potential for recovery of the fauna to the level characteristic of other Lake Erie river mouth is precluded by irretrievable human induced conditions. However, the ship channel is used by fish as a migratory route in the spring months. This seasonal and stream flow related uses shall be recognized and protected through this rule." The section E(3)(a) of the rule describes the following exception related to dissolved oxygen, "The limited resource water dissolved oxygen criterion shall be 1.5 mg/L minimum. No dissolved oxygen average criteria apply." Section E(5) states "These standards reflect the desire for restoring and maintaining multiple uses of the ship channel expressed by the Cuyahoga River Remedial Action Plan Coordinating Committee. All parties, private and public, who contribute to the dissolved oxygen problem may share a responsibility in the study and attainment of these standards. The dissolved oxygen criteria established in paragraph (E)(3) of this rule are intended to be the minimum planning targets for the remedial action planning process to use in evaluating beneficial use restoration."
>
> "Based on the Cuyahoga rule, we believe it is appropriate to utilize the Cuyahoga shipping channel dissolved oxygen criteria as the BUI restoration target for the federally designated shipping channels in the Black, Maumee and Ashtabula AOCs. It should be noted that if waters have more than one designated use then the lowest target applies and for lacustuary waters with no other use designation, dissolved oxygen will not be evaluated."

According to the data presented in this report, substantial gains have been made in DO in the Cuyahoga AOC including the lower river, ship channel and harbor. Corroborating data in the near future would allow the revisiting and removal of this impairment and change in the administrative code (OAC) to reflect and insure improvements can persist in the future.

Assessing the progress on plankton populations against BUI 13 is a bit of a tricky issue. This BUI was originally intended for application in the Maumee Bay area of the Maumee AOC and was not applied to other Ohio AOCs. However, the assessments of phyto- and zoo-plankton are important in all lower river and lacustuary areas along the lakeshore as these are primary and early life production zones and nursery areas. The International Joint Commission views the BUI 13 impairment as one that addresses the effects of toxicity on plankton communities, populations and densities (OEPA 2014). The Ohio Listing Guideline in the latest OEPA Delisting Guidance links the plankton impairment to the fish community assessment (OEPA 2014) since direct indicators have not been established. Data collection, analyses and summaries have been lacking for Ohio's harbors and lower rivers. As more data of this type is collected and reported on, researchers can highlight differences and infer deficiencies or trophic status of different Lake Erie sub-watersheds regarding plankton production and quality.

With this study, we have begun to describe plankton populations and densities in areas that are impaired by other physical and chemical factors (including legacy contaminants), as in the case of the Cuyahoga, and in other less-impaired areas like the Grand River. While this study will not create a case for a new standard to be applied for BUI 13, there is adequate data to support an evaluation on the quality and quantity of phytoplankton and zooplankton observed in our samples across the two different Lake Erie watersheds. As it relates to BUI 3 (fish communities), and BUI 8 (eutrophication and undesirable algae), the status of the plankton populations and the (eventual) BUI 13 metric should be associated with food quality: densities of edible vs. nuisance (i.e. blue green) algae and densities of edible zooplankton and copepods.

Further detailed analyses beyond this project can evaluate seasonal availability of plankton for larval and juvenile fish species of interest, Dreissenid mussel veliger densities, and application of HABs to toxicity effects and impairments to biotic communities.

Our sample data and the analyses presented by Culver et al. (2015) highlight the great diversity in the phytoplankton and zooplankton samples. Taxonomic diversity of zooplankton was very high (27 cladoceran species, 22 copepod species, and 18 rotifer genera, plus dreissenid veligers; Culver et al. 2015). Copepod and cladoceran crustaceans were generally dominant in the zooplankton densities and biomass, with occasional large seasonal contributions from rotifers and veligers. Cyanophytes (blue green algae), including *Microcystis*, were seasonally predominant in the late summer and early fall, although *Microcystis* did persist or predominate at other times of the year as well (see Figure 20-23 in the Results).

In comparisons between the Cuyahoga River stations and Grand River stations for the two years where we have common data (2013 and 2014), there were mixed results. There was not a significant trend in *Microcystis* between the two water areas: the mean densities of *Microcystis* measured at Cuyahoga stations was 74 individuals per ml in 2013 (range: 0-564) and 55 per ml in 2014 (range: 0-211), while at Grand River stations it was 33 individuals per ml in 2013 (range: 0-173) and 72 per ml in 2014 (range: 0-303). During high discharge years like 2011, cyanobacteria biomass (mainly as *Microcystis*) was higher at Cuyahoga stations than nearshore Lake Erie stations, and often cyanobacteria densities exceeded densities of beneficial diatoms, green algae, and flagellates (Culver, pers. comm., and in 2015 presentation to ODNR at the OSU-AEL annual research review). Densities of the beneficial plankton in the Grand River usually exceeded those observed in the Cuyahoga River, while overall Cyanophyte (blue green algae) densities were higher in the Cuyahoga compared to the Grand. These two observations allow a relative comparison of performance and impairment between the two systems; *i.e.*, the Cuyahoga is more impaired than the Grand, but without more data in these and other systems, we cannot say if that impairment is significant and if there is any trending performance in these systems.

The last impairment, and probably the most significant component of this project that requires further attention, is BUI 14 – loss of fish (and wildlife) habitat. The wildlife habitat portion of this BUI has been addressed in other projects, and current conditions have been deemed to meet guidelines for delisting. Avian and terrestrial wildlife populations for nearshore urban and suburban habitats are established or thriving.

The contrast of conditions is observed in the aquatic habitat, which is severely impaired by annual dredging and maintenance of a ship channel and deep-draft harbor for the use of ships that transit within and between the Great Lakes, St. Lawrence River, and Atlantic Ocean for regional and international commerce. This project evaluated aquatic habitat quality in a number of ways: depth, shoreline type and function, slope, substrate composition, vegetation type and density, thermal, DO, and chemical parameters, and food availability. All of these parameters described bring a holistic picture of habitat perturbation to the physical, chemical and biological integrity of the system (IJC 1991).

For this BUI metric, the State of Ohio delisting criteria only use the QHEI and/or L-QHEI scores to determine if the habitat is impaired (OEPA 1989, 2014). Recent reviews and the re-worked BUI definitions have removed a QHEI threshold score for Limited Resource Waters (LRWs), like those areas defined for the Cuyahoga Ship Channel, Old Channel and Cleveland Harbor (the lower area of the defined AOC). OEPA (2014) states that the LRW designation and lack of QHEI targets are not applicable because:

> "(The) LRW designations are waters that have been found to lack the potential for any resemblance of any other aquatic life habitat as determined by the biological criteria through a use attainability analysis such that the extant fauna is substantially degraded and that the potential for recovery of the fauna to the level characteristic of any other aquatic life habitat is realistically precluded to natural background conditions or irretrievable human-induced conditions."

OEPA (2014) also states that for Modified Warmwater Habitat attainment, QHEI/L-QHEI scores of 50 or above should be maintained and represents a level of aquatic habitat required to meet fish community quality and health. Yet in the next sentence, it is stated (OEPA 2014): "that if the MWH cannot attain the target due to degradation or physical modifications that cannot be reasonably and cost effectively rectified, then these waters should not preclude the BUI from being removed in the AOC." It appears that accommodations are in place for both LRWs and MWHs to allow removal of the BUI if ship channel depth maintenance and shore hardening are expected to be perpetuated in the future.

QHEI scores from the study area illustrate the magnitude of the impairment: Our QHEI scores and NEORSD QHEI scores were consistently in the 20s and 30s in the ship channel and old channel locations; river miles (RM) 0-5.9. In NEORSD sites upstream of the ship channel at RMs 7-16, QHEI scores rebounded to the 60s-70s, reflecting more natural riverine conditions. The impairments in the ship channel were reflected in reduced scores for Substrate, Cover, Riffle/Run, and Current/Gradient components. This reduction in habitat scores is to be expected when the ship channel is typically a dredged, 23-foot (7m) deep, "U" shaped channel throughout its 5.5 mile course from Arcelor-Mittal to the river mouth and out through the harbor. The transition areas along the land-water interface in the ship channel old channel and most of the harbor remain clay-silt-muck and drop-offs to the dredge channel are steep (or vertical). The lack of vegetated, littoral or coarse-grained habitat is pervasive.

The dredged ship channel lacks habitat diversity, bottom and shore complexity, any appreciable areas of shallow water habitat, and substantial cover habitat. Sediments are mostly clay and silt based. Sands and gravels are some of the first materials to rain out and settle in the upper ship channel, and they are likely the first materials to be removed through the annual dredging process. Cover habitat, in the form of logs, root wads, shore brush and submersed or emergent vegetation are scarce in the dredged channel. Many logs that enter the ship channel are removed to ensure safe navigation conditions. A few backwater marina, small stream entrances, and abandoned areas or neglected properties provide some shallow water refuge and woody or vegetated cover. Reversion to natural conditions is a healing part of the restoration process.

Lack of gradient and current diversity (even inner and outer river bends are uniform in stream depth and velocity) impair the natural river function of the ship channel, making it appear more like a stagnant reservoir. Ubiquitous shore armoring, in the form of steel sheetpile or poured or placed concrete, harnesses the river channel and the lake shoreline in most places. Energy in the river, stays in the river, and does not dissipate up the shoreline; it just reverberates. Large stone or concrete blocks armor breakwalls or revetments along the lakeshore and in marinas. These armored structures provide little to no transition zones of shallow water to the uniform dredged depths. The vertical hardening does not provide substantial dissipation or release of water energy in the narrow channels or the land/water interface. Large ships provide periodic episodes of destructive energy forces through bow waves and lateral forces from thrusters and prop wash as they maneuver upstream, downstream, and alongside mooring areas.

On the other hand, our cursory review of the habitat of the "middle section" of the Cuyahoga River, from the State Route 82 dam in Brecksville down to the first riffle below the Harvard-

Dennison bridge, confirmed what was presented in the NEORSD QHEI values. This stretch of the Cuyahoga River habitat is largely reverted to riffle-pool-run development with natural meanders, albeit within a narrow corridor dropped in a variety of upland habitats that range from urban to suburban to rural (within the confines of the Cuyahoga Valley National Park). Habitat quality is as good as attainable for Modified Warmwater Habitat in a developed urban and suburban watershed. Urban, suburban and agricultural inputs all affect the AOC watershed in these locations, yet habitat diversity is flourishing and MWH index thresholds are exceeded. Conditions in this river reach are exemplifying habitat and aquatic community recovery beyond past impairments. All is not perfect, though, as critical issues such as flooding episodes, and silt, nutrient and bacterial inputs still remain and need to be addressed.

While dredging is a direct effect on habitat modifications in the ship channel, the pervasive anthropogenic effects throughout this watershed have a demonstrable effect on water quality and quantity- which is a significant component of the habitat impairments observed in ship channel as well. These effects can then have direct impacts on aquatic community diversity and health. Aquatic habitat deficiencies in the lower river and harbor, if allowed to persist, will keep aquatic communities, and specifically fish populations, from recovering to levels observed in more natural, neighboring Lake Erie watersheds. Holistic improvements to water quality and quantity parameters, and prescribed habitat refugia placement, implemented throughout the watershed, will go a long way to promoting healthy aquatic communities and removal of this BUI.

Given our evaluations of habitat in the project study area, there is still substantial progress that can and must be made to attain a suitable and sufficient level of aquatic habitat quality needed to support healthy aquatic communities and achieve removal of this BUI. I disagree that we as regulators and interested parties supporting or implementing restoration should abandon any attempts to secure more diverse and healthy habitats as refugia from the impaired conditions that will persist in the main part of the ship channel as long as annual dredging is desired. Simple tactics can be employed to improve habitat complexity and maintain continued ship traffic.

Opportunities for restoration and management implications

Local, state and national interested parties have adjoined efforts to restore the Cuyahoga River and Cleveland Harbor and seek removal of the BUIs and the AOC, through implementing land- and water-based habitat improvement projects. Land management, river corridor vegetated buffer restoration, and water control efforts at the watershed level should continue in the future and will have direct bearing on the water quality and water quantity components of aquatic habitat in the receiving areas of the lower river, old channel and harbor. These opportunities should continue to be pursued as they have a holistic effect on baseline watershed conditions and terrestrial and aquatic community health; sediment and nutrient inputs, and water volume and energy are expressed and controlled at this level.

The Port of Cleveland is also proposing an in-stream sediment trap and removal project to be implemented in the middle river section of the Cuyahoga River. As proposed, this in-stream structure will trap much of the bedload moving downstream and may reduce the need for dredging in the ship channel. It remains to be seen if there are any improvements in suspended solids and turbidity in the lower river from implementing this sediment removal method. Another unknown that needs to be evaluated is any loss of riverine habitat or changing conditions in the middle section of the river with the installation of this structure and its operation.

Some interested government agencies or groups have implemented in-stream and riverbank habitat improvement projects in the Cuyahoga River AOC (ship channel and harbor) in the last several years with varying success. Habitat restoration projects have also been implemented in the Black River and Ashtabula River AOCs. In evaluation of these existing projects, two general trends have emerged – one method that implements changes to the depth, slope and physical habitat, while another method adds habitat diversity to existing infrastructure and maintains river depth and bank slope.

Habitat structure placement in the lower Cuyahoga River AOC has been difficult and has not enjoyed a modicum of success. Cuyahoga County and RAP groups have tried placement of floating island structures, Bee Mats, and hanging vegetation bags on the vertical sheetpile at select locations in the Cuyahoga ship channel over the last decade. Emergent vegetation was slow in becoming established, and the structures failed over short time periods due to changes in water levels, water energy pulses from floods, ice and ship traffic. Structures flipped or became dislodged from these aforementioned stressors, flotsam, jetsam and bird roosting or disturbances and failing attachments. These hanging structures, while attached to the sheetpile, did provide minimal cover and habitat diversity (but offered no depth relief from the maximum dredged depths). Our electrofishing and food web samples did not reflect any improvements of fish, plankton or benthic populations in these habitat locations. There were some confounding, underlying problems observed, as these habitat structures were placed adjacent to a major (industrial) outfall that may have been affecting ambient conditions through thermal loading (as evidenced by our project data recordings).

New structure placement projects are underway at other sites in the Cuyahoga AOC ship channel that work within the crenellations (bends) and infrastructure of the existing steel sheetpile. These habitat structures are placed in and on the sheetpile and hang down and into the river channel, providing habitat complexity and cover refugia. Continued research will evaluate the success of these hanging structures in providing additional aquatic habitat and community restoration and sustaining this habitat diversity over time in the "working river." This GLRI project's abiotic, habitat, and biotic sampling measures and data can provide a baseline resource and standardized measuring methods/techniques to assess potential improvements realized from these new habitat projects.

Other habitat restoration projections in the Cuyahoga AOC have addressed land forming activities along the riverbank. The Scranton peninsula project has restored and aims to protect and enhance shallow water habitat along the left descending bank of the river below I-90 past the Carnegie Ave bridge. This project has remediated the old Scaravelli marina and nearby lands by re-contouring and replanting uplands, planting emergent vegetation at the land-water interface, and providing a buffer between the shallow water areas and the main dredged river channel. Our evaluations of this project area have shown improved shallow water habitat being utilized by both resident and lake-transient fish species. Our highest fish catches and diversity in the ship channel were observed in this part of the river. Given that the restoration in this area is only a few years old, further recovery and improvements are expected as this area naturally grows back in or is replanted with vegetation.

Another shallow water habitat restoration activity currently underway in the Cuyahoga AOC is an ODOT-sponsored project under the new I-90 bridge spans (see Figure 28). This project involves installing dish-shaped ponds behind the sheetpile, with vertical openings cut in the sheetpile for small fish and aquatic biota movement into and out of the newly-developed aquatic habitat from the main river channel. These new areas add shallow water complexity to the river system. Evaluations should be forthcoming to gauge their success in habitat development, fish attraction and usage. These areas, established with controlled (rather than open) connectivity to the river and developed behind the main river sheetpile, may be an important method to establish more shallow water habitat areas that are somewhat protected from the main river energy forces and invasive nuisance species like common Carp. Evaluation and design improvement can further efforts (and funded projects) to establish diverse littoral riverine and nearshore habitats.

Ashtabula and Black AOC habitat projects have enjoyed success in restoring natural conditions and aquatic community health. Shallow water areas with extensive cover and habitat diversity were developed along margins of the dredged rivers, and riverine and Lake Erie migratory species have been observed in these restored areas (OEPA 2015). Hardened shorelines and riverbanks were replaced with native cover, and shore and bottom type diversity was enhanced. Aquatic communities responded accordingly over the course of just a few years.

The US Army Corps of Engineers completed a habitat structure project on the Cleveland harbor breakwall by installing shallow water benches and dimple-designed concrete stone blocks in limited locations. Our electrofishing transects that included these areas did not see any significant increases of fish populations in along these structures. Their limited application in the larger scope of the expansive harbor may have just moved or concentrated local fish into these bench areas from adjacent locations or travel paths. These slab-type benches did not appear to be effective habitat refugia from the lake and harbor wave and ship energy. The benches provided additional shallow water habitat, but habitat complexity was still lacking. The dimples embedded in the placed concrete blocks appeared too small to promote habitat diversity and complexity, and also showed no effect on energy dissipation or protection. No aquatic vegetation was established in these areas, and the increase in shallow water habitat was minimal in scope to the entire armored area in the harbor. Variable sizes of stone, rip-rap and concrete “jacks” used elsewhere along the breakwall provide more habitat diversity and complexity and could absorb wave and ship energy. Shallow water development and habitat restoration in a larger scale along the breakwall and in adjacent nearshore and harbor locales has been discussed during lakefront planning over the last two decades (Roger Thoma, pers. comm.; EcoCity Cleveland 2002), and it should be addressed as an option for habitat improvement and aquatic community restoration in the future.

One of the surprise findings observed in our study area was the habitat recovery and fish attraction to rip-rap placed as bank stabilization on Arcelor-Mittal property near the head of the ship channel at river mile 5.4. Juvenile and adult fish were sampled in this area after large rip-rap stone was placed along the bank and allowed to extend out into the river channel, providing some shallow water habitat complexity. IBIs responded accordingly, increasing from the high teens and lower 20s to the upper 20s to low 30s; a consistent, measurable increase from a relatively small, simple activity that increased shallow water and aquatic community diversity. These results mirrored what we observed throughout the AOC: fish communities were more diverse and abundant in or adjacent to complex, shallow water habitats with low to moderate levels of aquatic vegetation.

Based on the data obtained in this project, suggested methods for future habitat and watershed improvements in the Cuyahoga AOC should be focused on habitat diversity and complexity, and improving components of water quality and quantity in the ship channel, old river channel, and harbor. Land-use management, river corridor, storm water management, and water treatment projects will affect system inputs. Habitat and streambank restoration/protection activities will address components that directly support aquatic communities in the AOC. Shallow water habitat expansion and recovery is essential.

As far as fisheries management directions and implications, we can assess current conditions and review fishery regulation levers that can be pulled to trigger improved fish community health and restored fisheries. Continued fish population and fishery assessments can determine community health and trends in status. Most of the benefits to the fish populations and fisheries will be borne by residual effects of the expansion or spreading of healthy lake and river populations into restored or recovered habitats, communities, or abiotic conditions, rather than direct fish stocking plans.

Protective measures deemed necessary to promote healthy regional fish populations are already in place. There is no need to pursue any immediate stocking plans for re-introduction of native fish species into the lower or middle parts of the Cuyahoga watershed at this time. Walleye, perch, basses, pike, sunfish, habitat-sensitive, pollution-intolerant species, and forage fish species have already been recorded throughout the region from the harbor up through the middle river. These (otherwise healthy) regional fish populations will expand into restored areas over time from the upper river sections and Lake Erie.

Abiotic properties and suitable habitat conditions appear to be the controlling factors in the restoration and recovery of fish populations in this area, rather than the standing stock (number or density of reproducing adults) or forage base of the fish populations in the region. Changing regional conditions (anthropogenic and climate) and expansion of nuisance/exotic species may also affect re-establishment of native species.

Recently Cuyahoga AOC focus group members from Cuyahoga River Restoration (formerly Cuyahoga River RAP), ODW, OEPA, Cleveland Metroparks, and NEORSD met to discuss fisheries targets for restoration in the study area. Representatives defined fish species that have been observed in the river and harbor, have become established in these areas, and would be expected to occur under a variety of river and habitat conditions from severely impaired to completely restored. One way that AOC impairment status and improving conditions was to be gauged was by evaluating larval/juvenile fish production on an annual (or other time bound) basis. We would expect to see fish production quality and quantity to increase with recovering conditions. The group then defined benchmark or indicator species that would show how the AOC is recovering (Table 12). The group expected that fish production for species identified at the first level would happen routinely on an annual basis, while those indicator species listed in the second level may not reproduce well every year. The third-level indicator species were those thought to better define “ideal” recovered or pristine conditions and would probably not be observed very often given the current status of the AOC. Continued evaluations and reporting by interested parties will gauge restoration and recovery status, documenting successes and failures.

Table 12. Benchmarks on the Cuyahoga AOC health/documented reproduction of tentative Indicator Species.

Achievement	Lake Transient Species:	Resident Species:	Forage fishes:
Level 1	White Sucker	Channel Catfish	Gizzard Shad
"Easy"	Shorthead Redhorse	Common Carp	Freshwater Drum
Level 2	White Perch / White Bass	Largemouth Bass	Emerald Shiner
"Intermediate"	Smallmouth Bass	Sunfish species	Brook Silverside
Level 3	Walleye	Smallmouth Bass	Rosyface Shiner
"Advanced"	Muskellunge	Northern Pike	Blacknose Dace
	Lake Sturgeon		

Also, until public access expansion in the lower river improves and fishery use/regulation issues (in the National Park) are addressed, and the AOC is released, we cannot promote expanding fishing opportunities such as Ohio Division of Wildlife Steelhead Trout stockings into the Cuyahoga River watershed at this time. Persistent water quality and hydraulic issues could affect survival and out-migration of stocked Steelhead yearlings; these appear to be the major in-stream hurdles at the present time. Internally, expanded ODW Steelhead hatchery production (and associated costs) and Lake Erie Committee approval of expanded annual Steelhead stockings into the Lake Erie watershed would have to be addressed by ODW. Impaired river conditions over a long period of the river fishing season would affect the quality of fishing conditions (and angler success) and the total number of fishable days.

Conclusions

This project has generated a wealth of data on abiotic and biotic conditions observed over the 2011-2014 study period in the Cuyahoga River, Cleveland Harbor, nearshore Lake Erie just outside of the breakwall and in a comparison stream, the Grand River, located 35 miles to the east of Cleveland. This data can be used as a snapshot to evaluate conditions during this time period, and by using similar evaluation methods, to document changes in the abiotic and biotic conditions observed in the study area over time, or during and after improvements or other impacts that have been recorded.

This project’s findings and databases are now a resource for activities that focus on river conditions and remediation opportunities in the portions of the Cuyahoga River AOC. By no means are the achievements measured and detailed enough to warrant removal of all current AOC impairments. However, this study, along with other recent work in the AOC, combined with changing AOC impairment criteria, have detailed that substantial progress has been made, and that impairments are not as formidable as they were in past decades. River segments and some of the delisting strategies have been met or are in partial attainment. Abiotic conditions show that there are suitable conditions above the ship channel, in the harbor, and in adjacent areas in nearshore Lake Erie to produce larval fish. Our samples documented that larval and juvenile fish are moving through and residing in the Cuyahoga ship channel and have been found in the area of the middle river immediately upstream of the ship channel. We have set some goals to be obtained or yardsticks to gauge performance for juvenile resident and transient fish production based on historic, current and future (target) river and watershed conditions. Warm- and cool-water transient species are using the lower river as a travel corridor between the lake and more suitable stream habitats in the middle river zone. Some warmwater resident fish species are beginning to become re-established or are flourishing in the middle river, harbor and nearshore areas. Also, resident fish species are becoming more established in areas of the ship channel and harbor where suitable shallow water habitat (or flowing water in the case of transient species) persists.

While there were some physical anomalies (DELTs) noted on a small proportion of the fish sampled in this project, overall, the relative health and condition of the fish observed was acceptable. Larger, older fish that have received longer periods of exposure to old legacy pollutants were the ones observed to be impacted the most. As future remediations are made, and conditions in the watershed continue to improve, we would expect that the young fish recruited into the adult populations experience less exposure and exhibit fewer anomalies. Larval and juvenile resident and transient fish species present in our samples reflect the potential for recovery and expansion as these aquatic conditions and habitat improve.

Water quality issues such as localized temperature spikes, high turbidity, high nutrient levels, and low flow/ stream velocity rates recorded across the years of this study illustrate the problems encountered with the lack of shallow water habitat. Compounding the issue of poor habitat quality is shore hardening and water energy/movement exacerbated by narrow river channels, vertical sheetpile and pulses of high velocity and pressure. Other agencies are addressing regulatory issues involving sediment and nutrient control, and excessive shoreline armoring; and steps are being forged to improve conditions throughout the watershed that can provide benefits to the aquatic community. These changes will need to take a long-run approach to realize improvements on a system-wide scale. Stringing together well-designed localized projects that work in harmony can go a long way to promoting the bigger picture of remediation throughout the AOC and beyond.

Access points to the river from the middle stretches just inside the northern edge of the Cuyahoga National Park downstream to the mouth are lacking and need further development as conditions improve and people choose to recreate in the river. Boat access areas (launch points) throughout the middle and lower river are inadequate. This inadequacy not only affects public access to the river for their use and enjoyment, but facilitates continued scientific monitoring and public interest in the health of the river system.

These persistent abiotic and infrastructure conditions and continued impairments make it difficult to initiate any new activities of fish or fisheries restoration or stocking projects at this time. Many challenges still exist, and hopefully this study will provide support and baseline data for future evaluations and efforts to improve the water and habitat quality, and more public access in the AOC and in the entire Cuyahoga watershed- with continued actions and progress made toward delisting and improving aquatic conditions. Improving conditions in the watershed will lead to a natural progression in the re-establishment of sensitive species, but additional work will be necessary to stem flourishing non-native and invasive species.

Future actions to remediate the lower section of the Cuyahoga River and Cleveland Harbor should address hydraulic thermal and nutrient issues, ship channel flow regime, excessive turbidity and suspended solids, watershed contributions to the ship channel “reservoir,” ameliorating nearshore and riverbank hardening, improving shallow water habitat complexity, and increasing public access. Without these water quality and habitat improvements, AOC impairments compared to typical big-river, modified warm water habitat will persist, and future restoration activities may not achieve their intended outcomes.

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Appendices

Appendix 1 – USGS gaging station data recorded in the study area during the study period 2011-2015.

Appendix 2 – Figures illustrating abiotic data recorded at study area data sonde locations in 2014.

Appendix 3 – Plankton data and OSU analyses for 2011-2014 project study area collections.

Appendix 4 – Fish IBI and Macroinvertebrate ICI data summaries and QHEI evaluations.

Appendix A – Data and report files generated, to be transmitted with final report;
See file: "Final Report Appendix A.docx"