**Accomplishments**

* What are the major goals of the project?

The overall project goal of the Lake Erie Center (LEC) NSF FSML (Field Station and Marine Labs) equipment grant was to implement a new environmental Sensor Network system that established the first carbon, energy, and hydrologic flux network within the Great Lakes – allowing researchers for the first time to begin to understand the carbon, energy and hydrologic budgets. Our Sensor Network is used to assess lake/bay/river changes and analyze key environmental patterns in western Lake Erie, which has the highest productivity and number of fishes of all Great Lakes basins, accompanied by the growing challenges of nutrient loadings, sedimentation, and harmful algal blooms. With our advantageous location and facilities at the LEC, this project has worked to measure the exchange of carbon dioxide and water between the lake surface and the atmosphere, as well as the key associated ecosystem parameters (e.g., microclimate and water properties) to support mechanistic explorations of Lake Erie.

This new Sensor Network was designed to significantly enhance the development of the LEC as an environmental research and education leader, serving as a state-of-the-art website and tour demonstration – located just next door to the popular Maumee Bay State Park. The LEC features a popular monthly public seminar series on environmental research, weekly
Major Activities:

Specific Objectives:

1. Establish a lake flux tower Sensor Network to investigate water, energy, and carbon budgets and evaluate their relationship to harmful algal blooms in Lake Erie.

2. Establish a custom mobile flux facility mounted on our research vessel to investigate the spatial distribution of fluxes from Lake Erie \textit{in situ}, including in areas of harmful algal blooms.

3. Work with NASA Glenn Research to employ remote sensing to investigate the spatial extent of the blooms.

What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?

This research project has built a real-time collaborative environmental Sensor Network to evaluate carbon/water cycling in the Great Lakes, providing fundamental data for understanding ecosystem and climate changes, which are being communicated to the scientific, agency, and educational communities and to the public. This Sensor Network joined our other existing flux towers on adjacent land and wetland sites to form an array, thus scaling up the flux measurements at broader spatial scales. All towers were equipped with the same flux sensors to assure comparability. Due to the large amount of CH4 fluxes from the coastal wetlands and agricultural fields, we added CH4 gas analyzers (LI7700 and LI7550) at those sites.

All data are being processed with the EC Processor developed at the LEES Lab (Noormet et al. 2008, http://research.eeescience.utoledo.edu/lees/ecp/ecp.html).

Algal pigment sensors (chlorophyll a, phycocyanin) have been deployed during the summers at the PermS1 (NOAA GLERL) and the PermS2 station, and on the mobile boat platform during this project. These sensors are being utilized in algal bloom areas to provide phytoplankton data at a much higher temporal resolution (1-30 minutes) than previously available from boat-based surveys (1-2 weeks). The combination of newly acquired algal pigment sensors, an absorption spectrometer and backscatter meter, combined with existing reflectance spectrometers have provided excellent ground supporting data for improving satellite algorithms in the optically complex western basin. These data are employed to evaluate and improve atmospheric corrections necessary for utilizing satellite and airborne data to accurately map the HAB biomass. They also are being used in the development of algorithms for satellite and airborne sensors.

During 2014, we have been further networking with the NOAA Great Lakes Environmental Research Laboratory (GLERL) for long-term assistance and integration of data from our Sensor Network.
Significant Results:

1. According to interpretations of our data on an annual perspective, both western Lake Erie monitoring sites showed that the Lake system acts as a small carbon sink.

2. NEE (net on-site vertical fluxes of C) were -16 and -74 gC m-2 month-1 at the Crib and Light sites, respectively, during the ice-free (spring-summer-fall) season.

3. There were four and five CO2 uptake months in the Crib and Light sites, respectively, and July was the maximum CO2 uptake month at both sites, with -28 and -72 gC m-2 month-1.

4. The methane flux at both Lake sites was less than that for the wetland site, but higher than measured at the cropland site.

5. The hourly values of the average diurnal courses of sensible heat (H) varied from -1 W m-2 to +30 W m-2.

6. The diurnal variation of latent heat flux (LE) at the Crib site did not show obvious diurnal courses, and that site showed no day or night variations. The maximum values (largest +130-150 W m-2 from April to July) were observed from the afternoon to the next morning, whereas the minimum (smallest 0-30 W m-2) occurred from late afternoon to the early morning.

7. From June through August, the sensible heat flux (H) in the lake was higher than for the other months, > 100 W m-2 throughout most of the day, while the minimum occurred from November through March, ranging from near 0 to < 50 W m-2.

8. Variation of LE at the Light site did not show an obvious diurnal course, but was higher at night from June to October than during the daytime.

9. We are working to complete analyses in gap-filling the annual carbon, water and energy fluxes in the Great Lakes. We plan to submit these results soon to a journal.

10. We are relating these results to conditions for harmful algal blooms.

11. We are working to further interface our long-term continued funding, networking, and reporting with the NOAA GLERL government laboratory in nearby Ann Arbor, Michigan.

In 2011, Lake Erie experienced the largest harmful algal bloom in its recorded history, with a peak intensity over three times greater than any previously observed bloom. Long-term trends in agricultural practices were found to be consistent with increasing phosphorus loading to the western basin of the lake, and these trends, coupled with meteorological conditions in spring 2011, produced record-breaking nutrient loads (see Mikalak, Bridgeman, et al. 2013, PNAS). An extended period of weak lake circulation then led to abnormally long residence times that incubated the bloom, and warm and quiescent conditions after bloom onset allowed algae to remain near the top of the water column and prevented flushing of nutrients from the system. In early August 2014, an algal bloom and weather conditions forced *Microcystis* and its toxin microcystin deep into the water column and into the Toledo City Water Intakes (at the crib site -Perm2- for our Sensor Network). This resulted in analyses of microcystin concentrations above the 1 ppb recommendation of the World Health Organization (WHO), leading to the recommendation by the City of Toledo that residents not drink the tap water. This 2-day closure of the “Toledo Water Crisis” affected some 500,000 people. We are integrating these data on algal blooms into our Sensor Network findings.
The two permanent Sensor Network stations have been working well, collecting data at 60 hertz. Data are transmitted in real time to the Lake Erie Center every 5 minutes. We have been using the mobile flux station on the Lake Erie Center’s Mayflier boat to measure carbon, water fluxes, and climatic variables spatially during the field season. In addition to the eddy covariance CO2 and H2O flux measurements, a Wetlabs ac-spectra hyperpectral absorption spectrometer (ACS) and a YSI 6600 water quality sonde simultaneously have been used to measure a vertical profile of the water column at each site. When combined with the flux system, the ACS and YSI sonde have been characterizing the composition of algal blooms in increased spatial resolution, and are providing necessary ground control for interpreting satellite images. These results are being combined with NASA moderate resolution spectrometer (MODIS), Hyperspectral imager for the coastal ocean (HICO) and NASA Glenn Research Center (GRC) airborne hyperspectral imager (HSI) to: 1) refine HAB identification algorithms, and 2) identify relationships between flux and bloom intensity (Ouyang, submitted).

We have been analyzing the data from the permanent flux towers in Lake Erie. A lookup table method is being used for data gap-filling to obtain continuous daily, monthly, and yearly carbon and water budgets, because the lake ecosystem differs from terrestrial ecosystems. In terrestrial ecosystems, carbon and water fluxes are directly connected to vegetation, and several mechanism models can be used for gap-filling. But in aquatic ecosystems, new methods are being verified. For the look-up table method, tables were created for each site so that missing values of carbon, latent heat flux \( LE \), and sensible heat flux \( H \) could be “looked-up” based on the environmental conditions associated with the missing data. An R code lookup table gap-filling procedure thus is being ground-truthed. This R code method is based on the concepts of mean diurnal variations and look-up tables reported in Falge et al. (2000) for filling half-hourly values of carbon, \( LE \) and \( H \). Specifically, this method is being used to fill target fluxes with similar conditions, from when photosynthetically active radiation (PAR), air temperature (Ta) and vapor pressure deficit (VPD) are available. We have tested this process using data from the wetland eddy-covariance flux tower.

Results showed that water heat storage comprises the largest energy balance component, and that energy balance constitutes an important knowledge gap that dominates the lake water cycle, according to our continuous eddy covariance measurements. Self-designed sensors and our updated program are allowing us to accomplish this goal.

Our team has been working to report and share our high frequency and long-term continuous data and results to the worldwide science community via the project website. In 2014, we laid the groundwork for assistance in this endeavor with NOAA GLERL scientists. We also have been communicating our results via meeting posters and presentations (e.g., AGU-American Geophysical Union, SFS-Society for Freshwater Sciences, and IAGLR-International Association of Great Lakes Researchers conferences), and publications. Postdoctoral fellow Changliang Shao has submitted a co-authored paper, “Eddy covariance measurement of carbon, latent and sensible heat fluxes from western Lake Erie”. We will integrate these temporal and spatial data to evaluate the carbon, water, and energy fluxes using a mechanistic approach for the first such study of the Lake Erie Basin.

Key outcomes or Other achievements:

1. Key outcomes include fundamental data for understanding greenhouse gas exchange in a large Lake ecosystem, as detailed under significant results.
2. We further integrated our Sensor Network into our NSF Gk-12 program in 2013-14, partnering with graduate fellows and high school teachers through “Graduate Fellows in High School STEM Education: An Environmental Science Learning
Community at the Land-Lake Ecosystem Interface. This effort has included seminars in our monthly evening seminar series, high school classroom exercises, and science fair projects (http://www.utoledo.edu/nsm/lec/gk12_grant).


7. Completed draft, in editing process: Z. Ouyang, Shao C., Chu H., Becker R., Chen J., Bridgeman T., and Stepien. C. Relating Chlorophyll-a to CO2 flux in the western Lake Erie at multiple time scales (draft finished, in revision and internal review)

8. Published Paper: “Michalak… Bridgeman, et al. 2013 “Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions” in PNAS. We have been relating our results for the carbon data to the findings for harmful algal blooms.


14. We plan to integrate our knowledge of the Lake environmental parameters through the Sensor Network with the occurrence and spread of emerging pathogens.

15. The above team also published: Pierce, L.R., J.C. Willey, V.V. Palsule, J. Yeo, B.S. Shepherd, E.L. Crawford, C.A. Stepien. 2013. Accurate detection and quantification of the fish Viral Hemorrhagic Septicemia virus (VHSv) with a two-
**What opportunities for training and professional development has the project provided?**

1. We trained 8 graduate fellows and 8 high school teachers in education applications and exercises associated with our Sensor Network through our NSF Gk-12 program, Graduate Fellows in High School STEM Education: An Environmental Science Learning Community at the Land-Lake Ecosystem Interface", whose research theme included application of the Sensor Network to high school classrooms.

2. Graduate fellows worked to produce video lesson plans posted on our Lake Erie Center GK-12 website for others to implement in their classrooms. These activities are located on the University of Toledo Lake Erie Center's website: (http://www.utoledo.edu/nsm/lec/gk12_grant/Lesson_Plans.html). Lesson plans and videos created by our fellows include: (a) "Using Infrared Thermometers as a Teaching Aid in K-12 Classrooms" (which introduces students to the concepts of heat conductivity and emissivity, using hand held infrared thermometers); (b) “Satellites” (which has students examine changes in land use over time using aerial photographs); (c) “Sticky Wall” (which teaches students how to break down scientific literature), and (d) “Infrared camera activity” (which demonstrates the differences between infrared and visible light).

3. We provided mentoring and training to our postdoctoral fellow, Dr. Changliang Shao, funded through the University of Toledo. We have been working with him to coordinate output and productivity from the Sensor Network system. Dr. Shao has been monitoring and upkeeping the equipment and coordinating the computer output. He began working on the Sensor Network project in winter 2012. He has worked closely with five members of the sensor team.

4. Teachers and students participating in the NSF Math and Science Partnership (MSP) grant LEADERS (Leadership for Educators: Academy for Driving Economic Revitalization in Science), NSF #0927996, have had the opportunity to use the Sensor Network as a possible project. The teachers have learned about the Sensor Network and have visited one of the flux towers. They brought that information into the classroom and encourage students to do research projects that involve the Sensor Network.

5. Undergraduate Research Focus on Sensor Network Projects through our NSF URM Program at the Lake Erie Center and main Campus: Undergraduate Research Students and Mentoring in Land-Lake Environmental Science. The goal of this URM program was to prepare 30 young minority scientists for graduate school in biology through hands-on
sustained independent environmental research, effective mentorship, and active engagement in a research learning community. Independent research by our URM students will analyze and develop solutions for urban, industrial, and agricultural impacts on our local terrestrial and aquatic ecosystem continuum. Several URM students and projects have focused on the Sensor Network.

6. A public lecture at the Lake Erie Center was focused on the Sensor Network theme: Dr. Jennifer Read, Executive Director, Great Lakes Observing System. "Measuring for Management: The Great Lakes Observing System a collaborator and facilitator of data collection, management and integration in the Great Lakes region". 10/17/13

7. Another Lake Erie Center public lecture on the Sensor Network theme: Dr. Chris Winslow, Ohio Sea Grant, Stone Laboratory, CLEAR, and GLAERC. "Lake Erie critical issues (e.g., invasive species, harmful algal blooms, dredging, and coastal economic development) and the work being done to address these concerns." 3/20/14

8. Graduate students who participated in the Sensor Network:
   - Lindsey Pierce, Ph.D. (Stepien lab): The evolution and detection of the fish Viral Hemorrhagic Septicemia virus (VHSV). Ph.D. Dissertation (December 2013).
   - Ouyang, Zutao (Chen and Becker labs), (PhD anticipated, Summer 2015)
   - Phoenix Golnick (Bridgeman lab) (MS anticipated, Summer 2015)
   - Ken Gibbons (Bridgeman lab) (MS anticipated, Summer 2015)

* How have the results been disseminated to communities of interest?

1. Real Time Data Dissemination: Data acquired by this sensor system are being archived in a database at the LEC and are being maintained by the LEC Communications and Technology Specialist. Real time data are planned for display on a web interface for users. (http://www.utoledo.edu/nsm/lec/sensor_network/index.html). Data are being formatted for inclusion in the GLEON database. Dr. Chen has been leading an open-to-the-public effort for managing and archiving the data from these sensors for broader uses by GLEON, FLUXNET, etc.

2. Sensor Network Project Focus for NSF GK-12 Program at the Lake Erie Center. Utilization of the real-time data and results from the Sensor Network was the one of the emphases of our Gk-12 program, featuring training for high school teachers and graduate fellows, high school classroom exercises, and science fair projects (http://www.utoledo.edu/nsm/lec/gk12_grant/gk12_main.html).

3. Graduate Fellows in High School STEM Research: An Environmental Science Learning Community at the Land-Lake Ecosystem Interface, partners advanced graduate students in STEM disciplines with high school teachers and their minority students to: (a) Generate student enthusiasm for STEM careers by engaging them in hands-on research into environmental problems; (b) Exchange STEM knowledge and pedagogies between graduate students and high school teachers resulting in cutting-edge environmental science content and increased teaching and communication skills; and (c) Develop hands-on solutions to environmental problems along schoolyard stream ecosystems feeding the Great Lakes. Partners include federal, state, and local environmental agencies. High school classroom activities were developed and disseminated that use the real-time Sensor Network.

4. Undergraduate Research Focus on Sensor Network Projects through our NSF URM Program at the Lake Erie Center and main Campus: Undergraduate Research Students and Mentoring in Land-Lake Environmental Science. The goal of this URM program was to prepare 30 young minority scientists for graduate school in biology through hands-on sustained independent environmental research, effective mentorship, and active engagement in a research learning community. Independent research by our URM students helped to analyze and develop solutions for urban, industrial, and agricultural impacts on our local terrestrial and aquatic ecosystem continuum. Several URM students and projects focused on the Sensor Network program.

5. Sensor Network Training through the NSF funded Math and Science Partnership grant called LEADERS (http://leaders.utoledo.edu). The LEADERS Program has been developing teacher leaders in project-based science on the topic of renewable energy. The teacher leaders then gave professional development in their districts on these same topics. During the class, the teacher leaders developed a project based on the Sensor Network, specifically the wetland tower.

6. A public lecture at the Lake Erie Center focused on the Sensor Network theme, Dr. Jennifer Read, Executive Director,
7. In 2011, Lake Erie experienced the largest harmful algal bloom in its recorded history, with a peak intensity over three times greater than any previously observed bloom. Long-term trends in agricultural practices were found to be consistent with increasing phosphorus loading to the western basin of the lake, and these trends, coupled with meteorological conditions in spring 2011, produced record-breaking nutrient loads (see Mikalak 2013, PNAS). An extended period of weak lake circulation then led to abnormally long residence times that incubated the bloom, and warm and quiescent conditions after bloom onset allowed algae to remain near the top of the water column and prevented flushing of nutrients from the system. In August 2014 another bloom led to a ban on the City of Toledo drinking water to 500,000 people. We have integrated such data on algal blooms into our Sensor Network findings.

8. Dr. Czajkowski and Dr. Becker presented the Sensor Network results at the Lake Erie Center joint Advisory board meeting on April 24, 2014.

9. Poster presentations on the results were disseminated at scientific conferences including GSA – Geophysical Society of America, SFS- Society of Freshwater Sciences, Freshwater gas exchange meeting, GLEON, and OBFS- Organization for Biological Field Stations/NAML-North American Marine Labs.

Supporting Files

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<td>Mobile Sensor Unit for greenhouse gasses that was built by the laboratory of Dr. Jiquan Chen for the Sensor Network, using these NSF FSML funds. This unit is mounted on the Lake Erie Center's R/V Mayflier and is used in conjunction with water quality mon</td>
<td>Carol Stepien</td>
<td>10/29/2014</td>
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<td>permanent stations.pdf</td>
<td>Locations and photos of our two permanent Sensor Network stations, established during this study.</td>
<td>Carol Stepien</td>
<td>10/29/2014</td>
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<td>2NSF annual report_LECSensor network2014_s kevin_CAS_FINAL.pdf</td>
<td>Detailed description of data and results from the Sensor Network project.</td>
<td>Carol Stepien</td>
<td>10/29/2014</td>
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Products

Books

Conference Papers and Presentations


Czajkowski, Becker, Shao, Chen, Stepieen, Bridgeman (2014). RESULTS From the Lake Erie Center LAND-LAKE SENSOR NETWORK. Lake Erie Center Joint Boards Meeting. Toledo, OH. Status = PUBLISHED; Acknowledgement of Federal Support = Yes


Inventions

Journals


Chaffin, J.D., T.B. Bridgeman, and D.L. Bade (2013). Nitrogen constrains the growth of late summer cyanobacterial blooms in Lake Erie. Advances in Microbiology. 3 16. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.4236/aim.2013.36A003


**Licenses**

**Other Products**

**Other Publications**

**Patents**

**Technologies or Techniques**

We developed a portable greenhouse gas sensor system for use on our research vessel, described in this report. We have disseminated this technology through our website, and to high school teachers and graduate students in our Gk-12 program.

**Thesis/Dissertations**


Pierce, L.R.. *The evolution and detection of the fish Viral Hemorrhagic Septicemia virus (VHSV)*. (2013). University of Toledo. Acknowledgement of Federal Support = Yes


**Websites**

Lake Erie Sensor Network-Data Gateway
The Lake Erie Center Sensor Network (LECSN) was designed to establish essential infrastructure to measure the exchange of carbon dioxide and water vapor between the lake surface and the atmosphere, as well as key microclimate and water quality parameters to support mechanistic exploration of Lake Erie.

**Land-Lake Sensor Network at the UT Lake Erie Center**

**Project plan:** This NSF FSML (Field Stations and Marine Laboratory) equipment award to the University of Toledo’s Lake Erie Center funded an environmental sensor network system to assess lake/bay/river changes and analyze key environmental patterns. The project is establishing the first carbon, energy, and hydrologic flux network within the Great Lakes – allowing researchers for the first time to understand the carbon, energy and hydrologic budgets. With our advantageous location and facilities at the LEC, this project’s goal was to measure the exchange of carbon dioxide and water between the lake surface and the atmosphere, as well as the key associated ecosystem parameters (e.g., microclimate and water properties) to support mechanistic explorations of Lake Erie. The sensor networks include two permanent monitoring stations installed on existing structures (the Toledo water intake crib and a NOAA buoy) and a shipboard station on the Lake Erie Center’s “Mayflyer” vessel to support essential experiments on Lake Erie. Findings are providing important comparison and exportation to aquatic systems worldwide. Some preliminary results of this project were recently highlighted on NSF’s website.

The new lake sensor network was linked with other existing flux towers in the terrestrial portions of the Maumee River Watershed, including the Oak Openings Savannah, a coastal wetland at the Lake Erie Shoreline, a cropland, and an urban flux tower. These clustered towers are permitting us to begin to understand the water-land interactions at the watershed scale and provide key cross-discipline education and research opportunities. The southern shore of Lake Erie and particularly Maumee Bay are intensely human-impacted systems due to high human population density, industrial activity, and agricultural runoff; for which this proposed sensor system network is invaluable. Many of our current research projects at the University of Toledo have immediate application such as tracking *E. coli* populations, monitoring harmful algal blooms (including the record algal bloom in August 2011, across the street from the LEC in Oregon, OH), remediating waste disposal sites, constructing wetlands, and enhancing sportfish ecology and population structure. Building on existing partnerships with agencies including USEPA, NOAA, USDA, USGS, NASA, USDA, USFWS, Great Lakes Fishery Commission, the Ohio, Michigan, Pennsylvania, and New York Departments of Natural Resources, and the Ontario Ministry of Natural Resources has allowed for rapid dissemination of information and high potential for implementation. These agencies have joined our "Environmental Sciences Learning Community at the Land-Lake Ecosystem Interface", and are aiding the proposed sensor network.

The new lake sensor network is significantly enhancing development of the LEC as an environmental research and education leader, serving as a state-of-the-art website and tour demonstration – located just next door to the popular Maumee Bay State Park. The LEC features a popular monthly public seminar series on environmental research, weekly public and school group tours, a NSF Gk-12 program for Graduate fellows in 8 local high schools (reaching 420 students per year), and a NSF URM Undergraduate Research and Mentoring program; all interfaced in a land-lake Environmental Science Learning Community that networks with the new sensor research program and our website. We focused the 2012-13 academic year of the GK-12 program on utilizing the sensor network data in the high school classrooms, beginning with the summer training course for our teachers and graduate fellows in the program. High school students also engaged in science fair projects utilizing the network.

**Monitoring the health of a great lake**

**NSF Research Highlight**
A one-of-a-kind sensor network created by the Lake Erie Center (LEC) provides real-time data on carbon dioxide (CO2), water and energy flow rates for the lake's inland aquatic ecosystem. The sensors measure flow rates using a cluster of eddy covariance towers. In the first two years of this project, the team discovered that western Lake Erie comprises a relatively small carbon source. The finding surprised the researchers because the lake is well known for its expansive and growing...
This research will help expand knowledge of how the environment interacts both locally and globally over the long term. The data collected from the network enables the team and community to understand:

how Lake Erie's fresh water and its connecting waterways interact with the environment,
how the massive algae blooms affect life in and around the area, and
how the system contributes to the global concentration of atmospheric CO2.

Based at the University of Toledo, the LEC is an interdisciplinary research and education center dedicated to solving environmental problems at the land-water interface and bay-lake exchanges in the Great Lakes, the world's largest freshwater ecosystem. Carol Stepien leads a team of researchers that includes Jiquan Chen, Richard Becker, Thomas Bridgeman and Kevin Czajkowski.

Supporting Files

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Participants/Organizations

What individuals have worked on the project?

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<tr>
<th>Name</th>
<th>Most Senior Project Role</th>
<th>Nearest Person Month Worked</th>
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<tr>
<td>Stepien, Carol</td>
<td>PD/PI</td>
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<td>Becker, Richard</td>
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<td>Shao, Changliang</td>
<td>Postdoctoral (scholar, fellow or other postdoctoral position)</td>
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<tr>
<td>Gibbons, Kenneth</td>
<td>Graduate Student (research assistant)</td>
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</tbody>
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Full details of individuals who have worked on the project:

Carol A Stepien  
Email: carol.stepien@utoledo.edu  
Most Senior Project Role: PD/PI  
Nearest Person Month Worked: 1  
Contribution to the Project: Dr. Stepien is the Director of the Lake Erie Center (LEC) and Distinguished University Professor of Ecology at the University of Toledo. She has coordinated and overseen the overall Lake Erie Center Environmental Sensor project. She attended the Organization for Biological Field Stations (OBFS) and North American Marine Lab conference at Woods Hole Marine Biological Laboratory, where she presented a poster on the LEC sensor network outcomes and discussed those with NSF program officer Dr. McCarthy. She also presented a poster on the results at the Joint Aquatic Sciences Meeting in Portland Oregon in May 2014. Dr. Stepien's Great LakesGenetics Laboratory (GLGL) of the Lake Erie Center focuses on working with federal and state agencies and other researchers to develop and apply genetic DNA markers for: (1) evaluating the population and biogeographic structure of native fishes in the Great Lakes and (2) resolving vector pathways, population dynamics, evolutionary relationships, and genetic time course of nonindigenous species invasions. The environmental sensor data collected through this sensor network project enhances work on larval fish transport and environmental conditions that may lead to genetic patterns and population divergence (http://www.utoledo.edu/nsm/lec/research/glgl/).  
Funding Support: University salary, NSF, USEPA GLRI, NOAA Sea Grant, USDA award  
International Collaboration: Yes, Canada  
International Travel: Yes, Canada - 0 years, 0 months, 7 days  

Richard H Becker  
Email: richard.becker@utoledo.edu  
Most Senior Project Role: Co PD/PI  
Nearest Person Month Worked: 1  
Contribution to the Project: Dr. Becker has been in charge of setting up data QA/QC procedures for this sensor network project. Dr. Becker’s research has assessed the accuracy of satellite algorithms for multiple sensors for chlorophyll-a for the optically complex Lake Erie and Lake Ontario (Becker 2008). He developed algorithms to map potentially toxic cyanobacteria in the lower Great Lakes using MODIS satellite data (Becker 2009). He also developed a watershed model for the Maumee River watershed to examine the effects of land use change on sediment in the river. (http://www.utoledo.edu/nsm/envsciences/faculty/becker.html)  
Funding Support: NSF, NOAA, NASA  
International Collaboration: No  
International Travel: No  

Thomas B Bridgeman  
Email: thomas.bridgeman@utoledo.edu  
Most Senior Project Role: Co PD/PI  
Nearest Person Month Worked: 1  
Contribution to the Project: Dr. Bridgeman’s involvement in the sensor network has interfaced his research on water-
quality conditions and changes in western Lake Erie to establish seasonal trends and understand the influence of the Maumee River in determining offshore water quality and in triggering harmful algal blooms. Data are compared with historic trends since the 1930s and are shared with agencies to improve understanding of lake-wide patterns and as baseline data for fish foraging experiments. His laboratory also tracks episodic events of hypoxia and algal blooms. Ongoing targeted studies investigate environmental factors that result in harmful algal blooms and stress of hypoxia on fish and mayfly larvae. ([http://www.utoledo.edu/nsm/lec/research/wq/index.html](http://www.utoledo.edu/nsm/lec/research/wq/index.html)).

**Funding Support:** NOAA, NSF

**International Collaboration:** Yes, Canada

**International Travel:** Yes, Canada - 0 years, 0 months, 7 days

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**Jiquan Chen**  
**Email:** jiquan.chen@utoledo.edu  
**Most Senior Project Role:** Co PD/PI  
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Dr. Chen oversees 9 eddy covariance flux towers in the eastern USA and 22 in China ([http://www.utoledo.edu/nsm/envsciences/faculty/chen.html](http://www.utoledo.edu/nsm/envsciences/faculty/chen.html)), and is the main researcher working on the carbon cycling in this sensor network project. Dr. Chen also has led the effort in developing an open-to-the-public effort for managing and archiving the data from these sensors for broader uses by GLEON, FLUXNET, etc. He directly supervises the day to day operations of the post-doctoral researcher and has been interpreting and leading the data analyses.

**Funding Support:** USFS, NSF, USDA

**International Collaboration:** Yes, China

**International Travel:** Yes, China - 0 years, 1 months, 0 days

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**Kevin P Czajkowski**  
**Email:** kczajko@utnet.utoledo.edu  
**Most Senior Project Role:** Co PD/PI  
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Dr. Czajkowski's focus on this project is spatial imaging through geographic information systems (GIS) and remote sensing. He has been developing and testing a method to map turbidity in Lake Erie using atmospherically correct AVHRR imagery for NOAA's CoastWatch Program. His laboratory also has been assessing the impacts of land use/land cover change on water quality using satellite imagery, digital elevation models, SSURGO data layers, and weather information. His laboratory also is collaborating with the Army Corps of Engineers (ACE), USDA, USGS, USEPA, Heidelberg College, and Ohio State University to determine source areas of non-point source pollution in the Maumee River watershed and Lake Erie, wetlands mapping (Torbick et al. 2006), and monitoring the impacts of sewage sludge including contributions to surface water E. coli contamination (Czajkowski et al. 2010). Dr. Czajkowski presented on the project results in Finland. Dr. Czjakowski’s website is: [http://www.utoledo.edu/llss/geography/facultystaff/deptfaculty/czajkowski.html](http://www.utoledo.edu/llss/geography/facultystaff/deptfaculty/czajkowski.html)

**Funding Support:** NSF Gk-12 (travel to Finland to present project results)

**International Collaboration:** Yes, Finland

**International Travel:** Yes, Finland - 0 years, 0 months, 7 days

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**Changliang Shao**  
**Email:** changliang.shao@utoledo.edu  
**Most Senior Project Role:** Postdoctoral (scholar, fellow or other postdoctoral position)
<table>
<thead>
<tr>
<th>Name</th>
<th>Email</th>
<th>Most Senior Project Role</th>
<th>Nearest Person Month Worked</th>
<th>Contribution to the Project</th>
<th>Funding Support</th>
<th>International Collaboration</th>
<th>International Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Shao</td>
<td><a href="mailto:kenneth.gibbons@rockets.utoledo.edu">kenneth.gibbons@rockets.utoledo.edu</a></td>
<td>Graduate Student (research assistant)</td>
<td>3</td>
<td>Collected water quality and harmful algal bloom data under the guidance of Dr. Bridgeman.</td>
<td>University of Toledo Matching Funds for the Sensor Network</td>
<td>Yes, China</td>
<td>0 years, 1 months, 0 days</td>
</tr>
<tr>
<td>Kenneth Gibbons</td>
<td><a href="mailto:kenneth.gibbons@rockets.utoledo.edu">kenneth.gibbons@rockets.utoledo.edu</a></td>
<td>Graduate Student (research assistant)</td>
<td>2</td>
<td>Collected water quality data and harmful algal bloom data under the guidance of Dr. Bridgeman.</td>
<td>Teaching assistant, research assistant.</td>
<td>Yes, Canada</td>
<td>0 years, 0 months, 4 days</td>
</tr>
<tr>
<td>Phoenix Golnick</td>
<td><a href="mailto:phoenix.golnick@rockets.utoledo.edu">phoenix.golnick@rockets.utoledo.edu</a></td>
<td>Graduate Student (research assistant)</td>
<td>2</td>
<td>Assisted in maintenance of Lake Tower. Participated in research cruises. Ouyang has been responsible for the operation of the AC-S absorption spectrometer that is in use simultaneous with the mobile flux station measurements.</td>
<td>University of Toledo</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Ouyang Zutao</td>
<td><a href="mailto:ouyang.zutao@rockets.utoledo.edu">ouyang.zutao@rockets.utoledo.edu</a></td>
<td>Graduate Student (research assistant)</td>
<td>3</td>
<td>Assisted in maintenance of Lake Tower. Participated in research cruises. Ouyang has been responsible for the operation of the AC-S absorption spectrometer that is in use simultaneous with the mobile flux station measurements.</td>
<td>University of Toledo</td>
<td>No</td>
<td>No</td>
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</table>
What other organizations have been involved as partners?

<table>
<thead>
<tr>
<th>Name</th>
<th>Type of Partner Organization</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Toledo Water Department</td>
<td>State or Local Government</td>
<td>Toledo OH</td>
</tr>
<tr>
<td>GLEON</td>
<td>Other Nonprofits</td>
<td>web</td>
</tr>
<tr>
<td>NASA GLENN</td>
<td>Other Organizations (foreign or domestic)</td>
<td>Cleveland Ohio</td>
</tr>
<tr>
<td>NOAA GLERL</td>
<td>Other Organizations (foreign or domestic)</td>
<td>Ann Arbor Michigan</td>
</tr>
<tr>
<td>Ohio Dept. Natural Resources</td>
<td>State or Local Government</td>
<td>Sadusky Ohio</td>
</tr>
<tr>
<td>Organization for Biological Field Staitons</td>
<td>Other Nonprofits</td>
<td>web</td>
</tr>
<tr>
<td>Sylvania Public Schools</td>
<td>School or School Systems</td>
<td>Sylvania Ohio</td>
</tr>
<tr>
<td>Toledo Public Schools</td>
<td>School or School Systems</td>
<td>Toledo OH</td>
</tr>
<tr>
<td>USGS Great Lakes Science Center</td>
<td>Other Organizations (foreign or domestic)</td>
<td>Ann Arbor Michigan</td>
</tr>
</tbody>
</table>

Full details of organizations that have been involved as partners:

**City of Toledo Water Department**

**Organization Type:** State or Local Government  
**Organization Location:** Toledo OH

**Partner's Contribution to the Project:**
Facilities  
Personnel Exchanges

**More Detail on Partner and Contribution:** One of the permanent greenhouse gas sensor installations is on the Toledo water intake crib in Lake Erie, which is maintained and operated by the City of Toledo. We also installed water quality equipment there. City works accompany us monthly or more often to the station. We have assisted them and met with them to help assist following the Toledo "Water Crisis" in August 2014, when microcystin algal toxin shut down the Toledo water supply for 2 days.

**GLEON**

**Organization Type:** Other Nonprofits  
**Organization Location:** web

**Partner's Contribution to the Project:**
Other: Network

**More Detail on Partner and Contribution:** LEON (Global Lake Ecological Observatory Network). We joined GLEON and have been working on interfacing our network into GLEON (http://www.gleon.org/). We have continued to interface with GLEON and Dr. Czajkowski presented at the GLEON conference in Finland.
NASA GLENN

**Organization Type:** Other Organizations (foreign or domestic)

**Organization Location:** Cleveland Ohio

**Partner's Contribution to the Project:**
In-Kind Support
Facilities
Collaborative Research
Personnel Exchanges

**More Detail on Partner and Contribution:** NASA Glenn Research Center Ecosystem Monitoring Program. NASA Glenn Research Center in Cleveland, Ohio in collaboration with Bowling Green State University are working with the University of Toledo to utilize remote sensing to link the tower observations to the lake and surrounding area. Dr. John Lekki from NASA Glenn is the lead scientist developing their aircraft remote sensing initiative. Dr. Lekki is leading a group of scientists, including Gary Hunter, Frank Vergili, Lawrence Greer, Roger Tokars, Aaron Swank, Robert Romanofsky, Laura Evans, Obadiah Kegege, James Scott to develop aerial remote sensing with aircraft and unmanned aircraft system called the Aerial Investigation of the Great Lakes Ecosystems (AIGLE) project to study the Lake Erie ecosystem. NASA Glenn's assets include an advanced hyperspectral imaging (HSI) system, Microelectrome-chanical Systems (MEMS)-based Chemical Sensor Array and four manned aircraft. The sensors sniff out trace gas species as the aircraft flies. These observations are being linked to the University of Toledo's in situ tower observations and remote sensing imagery. The aircraft have the capability to observe carbon dioxide, carbon monoxide, methane, nitrogen oxides and sulfur dioxide. The sensors at NASA Glenn complement the sensors set up during this proposal to allow simultaneous measurements at individual locations both in the water and directly above the water, and at a larger scale from aircraft. During summer 2014, scientists from NASA Glenn conducted overflights simultaneous with acquisition from the mobile sensor system.

NOAA GLERL

**Organization Type:** Other Organizations (foreign or domestic)

**Organization Location:** Ann Arbor Michigan

**Partner's Contribution to the Project:**
In-Kind Support
Facilities
Collaborative Research
Personnel Exchanges

**More Detail on Partner and Contribution:** NOAA GLERL lab is partnering with our sensor network. We added our equipment to a NOAA buoy, and they have helped to maintain and service our system. We have several ongoing water quality and monitoring projects with their researchers, many of whom serve on our graduate student committees. The NOAA GLERL lab is located about 45 minutes from University of Toledo, facilitating collaborations.

Ohio Dept. Natural Resources

**Organization Type:** State or Local Government

**Organization Location:** Sadusky Ohio

**Partner's Contribution to the Project:**
In-Kind Support
Collaborative Research

**More Detail on Partner and Contribution:** We partner closely with ODNR scientists and managers on many Lake Erie projects, including this sensor network.
Organization for Biological Field Stations

**Organization Type:** Other Nonprofits  
**Organization Location:** web

**Partner's Contribution to the Project:**  
Other: Dissemination & Sharing

**More Detail on Partner and Contribution:** The University of Toledo's Lake Erie Center is an active member of the OBFS. In September 2014, Dr. Stepien traveled to the host Marine Biological Laboratory at Woods Hole Mass. to present a poster on our Lake Erie sensor network plans at the annual OBFS conference. She discussed the network and its updates and plans with NSF director Dr. McCartney.

Sylvania Public Schools

**Organization Type:** School or School Systems  
**Organization Location:** Sylvania Ohio

**Partner's Contribution to the Project:**  
Collaborative Research  
Personnel Exchanges

**More Detail on Partner and Contribution:** School system participating in the sensor network through the NSF Gk-12 program activities and training. High school students learn activities and lessons associated with the network. High school teacher Michelle Bogue participated throughout the 2013-4 academic year.

Toledo Public Schools

**Organization Type:** School or School Systems  
**Organization Location:** Toledo OH

**Partner's Contribution to the Project:**  
Facilities  
Collaborative Research  
Personnel Exchanges

**More Detail on Partner and Contribution:** Two Teachers and students from Toledo Public Schools have been learning about the sensor network on Lake Erie. Teachers have visited a flux tower and learned how it measures the energy budget, as well as examined the data from the mobile Lake station. The teachers introduced flux towers and the energy budget to their high school students. The Toledo Early College High School is involved in the NSF GK-12 program and Science Fair projects.

USGS Great Lakes Science Center

**Organization Type:** Other Organizations (foreign or domestic)  
**Organization Location:** Ann Arbor Michigan

**Partner's Contribution to the Project:**  
In-Kind Support  
Collaborative Research  
Personnel Exchanges
More Detail on Partner and Contribution: We collaborate with the USGS GLSC on many Great Lakes projects. Their scientists serve on several of our graduate students' committees. One project that is utilizing our sensor network data is their Huron-Erie Corridor (HEC) fish habitat restoration project. Dr. Stepien with Dr. Ed Roseman (USGS GLSC) co-edited a 2014 symposium volume on the results for the Journal of Great Lakes Research. Two of Dr. Stepien's graduate students have papers in the symposium issue.

Have other collaborators or contacts been involved? No

Impacts

What is the impact on the development of the principal discipline(s) of the project?

This project has built a real-time collaborative environmental Sensor Network to evaluate carbon/water cycling in the Great Lakes, providing fundamental data for understanding ecosystem and climate changes, which is being communicated to the scientific, agency, and educational communities and to the public. This Sensor Network joined our other existing flux towers on adjacent land and wetland sites to form an array, thus scaling up the flux measurements at broader spatial scales. All towers have been equipped with the same flux sensors to assure comparability. Due to the large amount of CH4 fluxes from the coastal wetlands and agricultural fields, we added CH4 gas analyzers (LI7700 and LI7550) at these sites. All data are processed using the EC_Processor developed at the LEES Lab (Noormet et al. 2008, http://research.ees.science.utoledo.edu/lees/ecp/ecp.html). Algal pigment sensors (chlorophyll a, phycocyanin) have been deployed at PermS1 (NOAA GLERL), at PermS2 (Toledo Water Intake) and on the mobile boat platform. The mobile boat platform is complemented by a Wetlabs AC-S absorption spectrometer to measure in-water optical properties.

These sensors are being used in bloom areas to provide phytoplankton data at a much higher temporal resolution (1-30 minutes) than previously available from boat-based surveys (1-2 weeks). The combination of newly acquired algal pigment sensors, an absorption spectrometer and backscatter meter, combined with existing reflectance spectrometers have been providing excellent ground supporting data for improving satellite algorithms in the optically complex western basin. These data are being used to evaluate and improve atmospheric corrections necessary for utilizing satellite and airborne data to accurately map the HAB biomass. They also are being employed in the development of algorithms for satellite and airborne sensors. We have been working on a long-term collaboration with NOAA GLERL to better transmit the data, and to secure long-term operating costs.

What is the impact on other disciplines?

Based on the Sensor Network, we anticipate a wide range of new and continuing contributions and collaborative efforts with scientists from academic institutions and applied research groups in other disciplines. Some initial questions involving our Sensor Network data have included:

- How much water is evaporated from the Lake Erie Basin and what are the driving forces for its dynamics at various temporal scales?
- Would changes in water chemistry, physical properties, ice conditions and hydrological cycle affect (and be affected) the water loss?
- How do changing climate and increasing extreme climate affect the fluxes of CO2, CH4, water, and energy within the western Lake Erie Basin, including water and adjacent landscapes?
- How do human activities (e.g., alternative land uses, urbanization) influence the overall functions of the basin?
- Will the basin respond to the changing climate similarly to other ecosystems worldwide? If not, why and how?
- How large are HAB blooms in the western basin at any given time? -What factors affect algal bloom size and dynamics?
- What portion of the carbon fluxes in the western Lake Erie basin is related to algal blooms?

We anticipate continuing long-term application and benefits from the Sensor Network.

What is the impact on the development of human resources?

We integrated our Sensor Network into our NSF Gk-12 program, for which the real-time data and results featured a summer
course training program for high school teachers and graduate fellows, year-round learning-community seminars in our monthly evening seminar series, high school classroom exercises, and science fair projects (http://www.utoledo.edu/nsm/lec/gk12_grant/gk12_main.html). Eight graduate fellows and eight high school teachers from seven schools along a rural-suburban-urban watershed gradient were engaged through this process. This included urban schools with high minority student proportions. Moreover, the graduate fellows designed high school classroom exercises, lesson plans, and videos on the system. Two Ph.D. student dissertations and an M.S. student thesis, and an in-progress Ph.D. dissertation and two in-progress M.S. theses have benefitted from the Sensor Network equipment, and a postdoctoral researcher was trained.

Our team members further submitted an NSF NRT (Graduate Research Training) proposal, which is in review: “NRT-DESE: Reframing STEM graduate education for future leaders of a data intensive world- A model using our environmental Sensor Network” (Stepien=PI, CoPIs= Drs. K. Czajkowski, J. Chen, C. Gruden, S. Qian). Submitted June 2014.

We also submitted an NSF REU (Research Experience for Undergraduates) proposal, which is in review: “NSF REU Site: Undergraduate Research and Mentoring - Using the Lake Erie Sensor Network to Study Land-Lake Ecological Linkages”, submitted August 2014 (PI=Stepien, coPI=K. Czajkowski), $323,000, 3 years.

What is the impact on physical resources that form infrastructure?

We installed the equipment and infrastructure for a permanent Sensor Network to analyze greenhouse gases and water exchange in western Lake Erie, as a prototype and model for the Laurentian Great Lakes and large lakes worldwide. We designed, built, and calibrated a unique mobile unit to use on our research vessel, to collect in situ data. We have been working on longer-term partnership with the NOAA GLERL lab to further build the Sensor Network and its impacts.

What is the impact on institutional resources that form infrastructure?

This Sensor Network project helped our university and research team to increase integration among laboratories, by sharing equipment and coordinating projects on a larger scale towards development of a real-time remote system. In 2014, this Network helped us to obtain further funding from our University President to order and pay for a new Research Vessel, collection equipment, a UAV system to collect algal pigment data, and a hydroacoustic imaging system to further the Sensor Network.

Leveraging the in-place Sensor Network, we submitted an NSF CUBESAT proposal together with our partners at NASA GRC and AFIT: Becker, R., (PI), Czajkowski, K., Black, J., (AFIT), Lekki, J. (GRC), Tokars, R. (GRC), (Co-Is), Collaborative Research: Cubesat: Spaceborne Hyperspectral Research Cubesat, NSF $894,545.

What is the impact on information resources that form infrastructure?

The Sensor Network is being disseminated through our server and website access in a developing interaction real-time format. Our postdoctoral scholar has been working on developing this dissemination forum. See http://www.utoledo.edu/nsm/lec/sensor_network/index.html We are further partnering with NOAA GLERL and GLOS in this effort.

What is the impact on technology transfer?

The NEON team at the University of Toledo, a founding member of NEON, Inc - (http://research.eeescience.utoledo.edu/lees/NEON/) will continue our collaborative effort in anticipated further broader impacts. The data from this Sensor Network are considered as the core information for any NEON site; and we are organizing them in alignment with NEON protocols.- NASA Glenn Research Center Ecosystem Monitoring Program. NASA Glenn Research Center in Cleveland, Ohio in collaboration with Bowling Green State University have been working with the University of Toledo to utilize remote sensing to link the tower observations to the lake and surrounding area. The summer field Gk-12 course on the Sensor Network took a field trip to NASA Glenn to interface with its scientists. These collaborations have continued with coordinated sampling and airborne measurements for the duration of the summer 2014 HAB bloom.

We are furthering technology transfer in conjunction with partners from NOAA GLERL and NASA Glenn.
What is the impact on society beyond science and technology?

We have been incorporating findings and the Sensor Network into our broader learning community at the Lake Erie Center, interfacing with the public and educators, including developing and disseminating lesson plans and YouTube educational videos.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them
Nothing to report.

Changes that have a significant impact on expenditures
Nothing to report.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.