The National Center for Water Quality Research at Heidelberg University
1969-2019
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Ken Baker
Heidelberg University, Tiffin OH

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Cover photos: Storm event-generated sediment plume moving into Lake Erie from Sandusky Bay, April 3, 2003. David Baker in 2004 and Jack Kramer in the late 1970s. Sampling station by Tindall Bridge near Fremont, OH. Autoanalyzer used to measure dissolved reactive phosphorus (DRP) and several other nutrients in water samples. Sample base containing algal-enriched water from the automated sampling station on Beaver Creek by the outflow of Grand Lake St. Marys, June 4, 2014.
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Foreword

In 1967, Dr. Tom Taylor and I, two second year staff at Heidelberg College, were able to implement an idea we had developed to incorporate environmental measurements into the laboratory sections of our introductory chemistry and biology courses. We had discussed the idea with our Academic Dean, Arthur Porter, who then recommended to President Terry Wickham that he allocate to us a $2,500 general purpose grant from the Esso Foundation to initiate the program. Beginning in the Fall of 1967 for a three-week period, the Introductory Biology Laboratory was organized into a water chemistry lab, consisting of three stations, one for doing colorimetric phosphorus testing, one for coliform bacterial testing, and one for biochemical oxygen demand testing, a measure of organic wastes in water. Each of the eight, 24-student laboratory sections was divided into three groups that rotated through the three stations over the three-week interval. Teaching staff, with the help of laboratory assistants, collected water samples twice a week at 24 locations along a 90-mile section of the Sandusky River, bracketing three municipal sewage treatment plants, and at four U.S. Geological Survey stream gages, as well as at the mouths of major tributaries. Dissolved oxygen and water temperature were also measured at the time of sample collection. Each laboratory section analyzed samples from 6 stations, along with a blind replicate; and each group of 8 students was divided into two so that duplicate analyses of each sample would be produced for the phosphorus, bacteria and oxygen demand tests. By borrowing equipment from other laboratories and utilizing funds available for the introductory laboratory, the analytical stations were equipped so that beginning students could obtain good data. The three-fold objectives of the laboratories were to learn about basic biological and chemical principles and current environmental issues while simultaneously producing useful environmental data. Student reaction to the river labs was very positive.

Although Heidelberg is primarily a teaching institution, the data generated by the River Studies Laboratories spawned the idea of conducting staff summer research on the Sandusky River. At that time, the Ohio Department of Natural Resources was developing the Northwest Ohio Water Development Plan. The plan focused on the construction of multi-purpose, up-ground, pumped-storage reservoirs. These reservoirs were to provide drinking water supplies, recreational opportunities, and water for augmenting stream flows to improve water quality during summer low flow periods. In 1968, I drafted a proposal to the Federal Water Pollution Control Administration to assess the water quality benefits of flow augmentation from a newly constructed up-ground reservoir in the Sandusky Watershed and received a grant to initiate studies during the summer of 1969. That summer turned out to be very wet with record setting floods, so the low flow studies were washed out. The summer crew that had been hired for the low flow studies nevertheless implemented the sampling program, and, after analyzing the data, noted that phosphorus export from the Sandusky Watershed was far greater than federal estimates at that time. Furthermore, the phosphorus export from these land-use -- runoff sources dwarfed the phosphorus inputs from the municipal sewage treatment plants in the watershed.
In the early 1970s, phosphorus loading to Lake Erie was recognized as a main cause of its severe eutrophication problems including central basin hypoxia, western basin algal blooms, and periphytic algal growths along its shorelines. We took our data regarding high phosphorus loads from agricultural runoff to the agricultural and Great Lakes research communities, governmental agencies, and foundations and were able to secure funds to expand our phosphorus transport studies in the Sandusky River. We modeled our program after the U.S. Geological Surveys’ sediment loading program, which involved daily samples on a year-round basis. We purchased and installed automatic water samplers at USGS stream gaging stations, with the samplers set to collect 4 samples per day. We also purchased automated analytic equipment that enabled weekly completion of sample analyses for an expanded set of nutrients, even for the large numbers of samples associated with storm runoff events. These procedures were up and running by 1974, and the U.S. Army Corps of Engineers funded an expansion of our tributary loading studies to other Lake Erie tributaries as part of its Lake Erie Wastewater Management Study. This tributary loading program, which began in 1974, is still in operation in 2019. It provides an internationally unique 45-year history of daily nutrient export from large agricultural watersheds to a major freshwater resource, in this case Lake Erie.

The monitoring and research programs we operate have expanded in numerous ways with multiple consequences.

- In 1978 we participated, along with Ohio State University and Buffalo State University of New York, in the 2-year Lake Erie Nearshore Study, giving us in-lake experience regarding the impacts of tributary loading on nearshore environments.
- With the onset of the nearshore study, a biological monitoring component was added to our monitoring program in the lake and subsequently in area streams.
- In 1980 we added pesticide monitoring to our tributary studies in response to the concerns of the environmental community that the use of no-till agriculture to reduce phosphorus loading would increase herbicide use, impacting both stream life and public water supplies.
- Our observations of herbicide concentrations in drinking water supplies hastened the development of federal drinking water standards for a new set of pesticides.
- Our observations of herbicides in rainwater led to the incorporation of herbicide analysis in ongoing rainfall deposition studies.
- In 1986, to help address widespread concerns regarding contamination in private rural wells, we initiated a cooperative private well testing program that through 2014 had analyzed nitrate concentrations in more than 61,000 well samples from 390 counties in 32 states and triazine herbicide concentrations in 23,000 private wells. This program has provided atlases of nitrate contamination for Ohio, Indiana and Kentucky and supported local ground water protection plans.
- As part of a pesticide monitoring program in Indiana private wells, we discovered a breakdown component of a certain class of herbicides that the U.S. Geological Survey has subsequently recognized as the major ground water contaminant from pesticide use in the Midwest. Fortunately, it is considered non-toxic.
In 1996 we organized a large-scale, successful, inter-institutional research study, the Lake Erie Agro-Ecosystem Study, that involved collaboration between researchers at Ohio State University, Case Western Reserve University, and Heidelberg.

In 1997 we founded (and since 2017 now host) the Sandusky River Watershed Coalition, a diverse group of stakeholders supporting programs for sustainable development of land and water resources in the Sandusky Watershed.

Our long-term nutrient loading studies have identified increased dissolved phosphorus export from agricultural watersheds as a major cause for the re-eutrophication of Lake Erie that began in the early 2000s.

We developed a now widely used stream flashiness index (the Richards-Baker Index) that quantifies trends in stream flashiness in response to changes in urban and agricultural land use.

In 2010 we conducted a study of the changing chemical composition of storm water masses as they moved through the lower Maumee River, Maumee Bay, and into the western basin of Lake Erie. This was a data-intensive study applying lagrangian analyses principles to non-steady state conditions with implications for depositional losses of particulate bioavailable phosphorus. In this study, we relied heavily on the resources of charter boat captains.

Our period of record nutrient data sets (182,862 water samples through September 2018) for nutrients and suspended sediments are freely available at our tributary loading website and are widely used by academic, governmental, and private sector scientists. For example, our long-term, detailed, nutrient loading data sets have been used extensively in the design of sampling, load calculation and trend analysis programs by governmental agencies.

In collaboration with certified crop advisors, we conducted a detailed study of phosphorus stratification in Sandusky Watershed soils to help assess causes of the increase in dissolved phosphorus loading to the lake.

We provide a data rich environment for both in-house and external model developers and for environmental extension programs related to agriculture and water quality.

Staff have recently presented seminars on our research and monitoring programs in foreign countries, including Canada, England, China (Hong Kong and Chong Qing), Australia, Portugal, Sweden, Vietnam, and the Philippines.

The laboratory has no significant endowment, receives no direct funding from Heidelberg University, and thus is totally dependent on grant income. We have developed a very broad funding base from governmental agencies, agricultural industries, environmental organizations, and various foundations by efficiently producing water quality data to support agricultural pollution abatement programs and to assess their effectiveness. A key to our efficiency comes from having skilled, dedicated, and hard-working technicians, using modern, highly automated analytical systems, linked together by a laboratory information system developed in-house to specifically support our operations. We operate an extensive quality control program to support our participation in collaborative monitoring programs. Since all funding comes from outside the college, senior staff are all full-time researchers, allowing them to interact with governmental, industrial, and academic scientists, serve on task forces, collaborate in the development...
of research proposals, organize research planning conferences, and annually provide numerous
environmental extension presentations to diverse audiences.

The laboratory interacts with Heidelberg students in multiple ways. We provide a limited number of
part-time lab technician jobs during the academic year and full-time work during summers. We support
numerous student independent research projects, and, where possible, share equipment with the science
departments to support both student and staff research projects. Lab staff have also taught a limited number
of special courses within Heidelberg’s environment studies curriculum. In addition to serving as our
business office, Heidelberg has facilitated the development of our programs by providing space in its
science buildings for our laboratories. Where our research grants include indirect cost payments,
Heidelberg allows us to use portions of that income as local matching funds or for updating equipment.
This further advances the efficiency of our operations and the competitiveness of our grant proposals.

The development of what is now called the National Center for Water Quality Research (NCWQR) at
Heidelberg University was largely a consequence of being in the right place at the right time with the right
people. Tiffin, OH is situated along the Sandusky River about 45 miles upstream from Sandusky Bay and
Lake Erie and surrounded by intensive row crop agriculture. As such, we were ideally located to work at
the interface of agricultural land use and water quality in streams and Lake Erie. Furthermore, the soils and
land use of the watersheds draining from the south into the western basin of Lake Erie are more prone to
nutrient runoff than any other location in the entire U.S.–Canadian Great Lakes Basin. The western basin
of Lake Erie is the southernmost, shallowest and warmest location in the Great Lakes Basin and
consequently the most vulnerable to the adverse impacts of nutrient loading. The lessons that can be
learned in collaboratively and successfully addressing the water quality problems in this region will be of
regional, national and international interest. We began our research programs at the time when the
problems of non-point pollution were just coming to light. In fact, our small research and monitoring
programs were positioned to shed considerable early light on the issues of nonpoint pollution.

This history of the NCWQR, while providing background in which the lab developed, focuses on the
third component that brought this lab to Heidelberg – the people who have populated the laboratory during
its first 50 years. They have all brought unique sets of skills to the laboratory as well as dedication to its
mission. I am delighted that Dr. Ken Baker (no relation), a recently retired Heidelberg biology professor,
has broadened his post retirement writing efforts beyond the preparation of a popular bi-weekly nature
column for local newspapers to include the writing of this NCWQR history. A history can be written from
many viewpoints. As an observer of the laboratory, rather than an insider, and with excellent research
skills, Ken provides an objective history of the lab that includes the viewpoints of researchers from other
institutions, agricultural advisors and farmers, Heidelberg faculty unaffiliated with the laboratory, student
research assistants, and the water lab staff. He finishes the history with a look into the future that is now
under the able direction of Dr. Laura Johnson who joined the staff in 2013 and became our Director in
2016. In as much as the “past is prologue to the future,” we trust that this history will serve as a solid base
for the next 50 years of work in the laboratory.

Dr. David Baker, Director Emeritus, NCWQR, July 2019
Acknowledgements

In December of 1968, David B. Baker, a young Assistant Professor in the Department of Biology at Heidelberg College in Tiffin Ohio, received word he had been awarded a grant of almost $48,000 from the Federal Water Pollution Control Administration, forerunner of the EPA, for a certain study on the Sandusky River he had envisioned. Among other things, the grant allowed for the purchase of various pieces of equipment and the hiring of Heidelberg Chemistry major Jack Kramer as a full-time research technician—employment to begin following his graduation in May 1969.

Some 48 years later, shortly before my own retirement after thirty years of teaching at the ‘Berg, I happened to bump into Dave’s wife in the University Bookstore. Peg likes the nature columns I write for several area newspapers and she wondered if I might be interested in working up a history of the National Center for Water Quality Research, the water studies lab that grew out of that first research project. Instead of running for the door, which might have been the more sensible thing to have done, I said, “Sure.”

As an ecologist, I had great respect for the work of the researchers and technicians on the top floor of Gillmor Hall, but my own interests lay in the structure of animal communities and I wasn’t much of a chemist. I’d have to up my game if I hoped to adequately represent what has made the work of the Lab so important. And there were boundless decisions to be made for which I was completely unprepared. Of the staff’s hundreds of publications, reports and presentations, which were of seminal importance meriting elaboration, which might be more briefly addressed or safely omitted from mention? How much technical detail needed to be discussed to make the Lab’s research comprehensible? Where do you draw the line between useful background information and tedious overkill? And what about controversial topics, personnel problems, financial challenges and unresolved hot-button issues?

It was only through many interviews with a wide array of people willing to share their differing perspectives on the story of—the Sandusky River Project, the River Studies Lab, the Water Quality lab and the National Center of Water Quality Research—that I began to see a way forward. At periodic intervals, I would meet with Dave Baker (no relation, by the way) to get his take on the stand-out issues of this or that decade, leaving his house with a stack of publications from his library. Pete Richards eventually got to recognize my phone number and Ken Krieger actually took a call from me in a New Orleans restaurant while on vacation with his wife, Susan. Both gentlemen, long-time researchers and former Directors of the Lab, were more than generous with their time. Jack Kramer, Ellen Ewing, Barb Merryfield and Nancy Miller, with over 170 years of combined experience in making the Water Lab happen, provided compelling insights into its evolution, its ups and downs, from the 1970s through the present day.

Laura Johnson, Rem Confessor, Aaron Roerdink and Jake Boehler each took more time than their packed schedules allowed to help me understand the dynamics at play as the Lab positions itself to move into its next fifty years. The perspectives of Tian Guo, Nate Manning and Nicole Kuhn, newest members of the NCWQR team, helped me feel the reality of that future. I thank Heidelberg’s President, Rob Huntington, along with V.P. for Administration and Business Affairs Hoa Nguyen and
Bryan Smith, Dean of the School of Natural Sciences, for their views on the same topic. Past and present Board of Trustees members Gary Bryenton, David Drake and Ralph Talmage offered important insights into the Trustees’ perspectives on the Lab and many of my former colleagues, now retired from Administration and the teaching faculty, helped me see the Lab of previous eras from other eyes than my own. Of these, I would especially thank Dave Weininger, Vicki Ohl, Jeanine Curns, Lee Martin, Bill Wickham, George Barlow and Percy Lilly.

There are so many people to thank for their time and insights and I know I’ll feel badly when I inevitably forget to mention the name of someone who allowed me to see the long story of the Water Lab in clearer light. Already, I see I have yet to thank Pat Hillmer, Tim Loftus, Josie Setzler, Rock Prater, John Crumrine, Tania Biswas and Laura Wallrabenstein, each of whom has played an important role in the Lab’s history and all of whom have graciously shared perspectives on their time there. Researchers from other institutions—Kevin King, Norm Fausey and Robyn Wilson; administrators of environmental advocacy and granting organizations—Gail Hesse, Jeff Reutters and Chris Winslow; agronomists and agricultural advisors—Beth Diesh, Brett Margraf, Greg LaBarge and Jerry Cunningham; and environmentally-motivated farmers like Doug Busdicker and Kurt Dunn have each offered invaluable insights on how the Water Lab’s work and staff members have been seen from outside of Heidelberg.

I must also thank the past and present student research assistants I’ve spoken with. My twenty interviews just scratched the surface of those I’d have liked to have spoken with, as a glance at Table 2 of Appendix A might suggest. Researchers from other institutions on their first visit to the Lab commonly voiced their astonishment over how Baker’s group had been able to amass such an amazing amount of data in the absence of a graduate program providing student research assistants. Indeed, without the help of many undergraduate student assistants collecting samples from the field and conducting analyses in the laboratory, the NCWQR’s immensely important legacy data set would have been very much smaller. The thoughts of these invaluable workers on their experience in the Water Lab and of its importance to their future careers rounded out my understanding of their role in the Lab’s history.

I am pleased to thank Bob Berg for his assistance in guiding me to numerous useful documents in Heidelberg’s archival collections, Rick Sherlock for acting as intermediary with the printer, and Peg Baker for two reasons. First, in 2007 she videotaped a collection of reminiscences with each of the NCWQR staff members that was the starting point for my research on the Lab. Second, it was Peg’s long-standing interest in having the history of this remarkable institution and its even more remarkable personnel being told that led to my efforts to do so. I apologize and take full responsibility for any errors of omission or other mistakes in relating that story.

Lastly, I will say that without the consistent encouragement (including the occasional boot in the derriere to get back to work) of my wife, this project would not have been completed in anything like its present form. Thank you, Deborah.

-Ken Baker, July 1, 2019
How is it that an internationally respected, state-of-the-art environmental research laboratory specializing in water quality studies came to exist—and thrive—in the setting of a small liberal arts college situated in a modest northwestern Ohio town surrounded by thousands of acres planted in corn and soybeans?

Prospective students and their parents on a first tour of Heidelberg University are suitably impressed when their Admission counselor gives them a peek at the facilities of the David B. Baker Environmental Science Laboratories taking up the entire third floor of Gillmor Science Complex. All that equipment, all those busy research chemists and biologists…it meets their expectation of what a modern, professionally-staffed science lab is supposed to look like.

Because that’s exactly what it is: a vibrant community of highly skilled and committed scientists and technicians employing state-of-the-art equipment in conducting a wide range of analytical and modeling studies in addressing an issue of great societal importance—the condition of the fresh water resources on which we all depend. And so the tour moves on, with the visitors nodding their heads appreciatively. But again, how did such a high-powered, independent research facility come to be housed at a small liberal arts college in Tiffin, Ohio? A simple timeline of events would adequately illustrate what happened and when in the Lab’s compelling history, but not how and why. Relating that story is the function of this narrative.

Mission Statement of the NCWQR

To promote the sustainable use of water and soil resources while striving to protect ecosystem integrity:

1. by accurately characterizing the impacts of nonpoint source pollution on regional water resources;
2. by helping develop and implement appropriate nonpoint source pollution abatement programs;
3. by evaluating the effectiveness of nonpoint source pollution programs in achieving water resource protection goals;
4. by utilizing adaptive management as a strategy for research on the environmental management of large-scale working watersheds; and
5. by communicating lessons learned from the above programs to the scientific community, policy makers, educators, stakeholder groups and the general public.
Evolution of the Laboratory’s Name

1967  The “River Labs” component of Heidelberg’s Introductory Biology courses
1969  The Sandusky River Project
1974  The River Studies Laboratory
1977  The Water Quality Laboratory
2002  The National Center for Water Quality Research

Chapter 1. The Late Sixties

Beginnings

In 1966, Heidelberg College graduate (1958) David B. Baker returned to his alma mater as the newest faculty member in the Department of Biology after having received his Ph.D. in plant physiology from the University of Michigan, performed a year-long Postdoc at the University of Tübingen, Germany and taught for two years as an Assistant Professor at Rutgers University. A large part of the young professor’s duties involved teaching a full-year Introductory Biology Course which included 8 laboratory sections. He soon developed some thoughts on how to liven up the freshman lab sequence by immersing students in a real-world research project assessing water quality in the region’s most prominent natural resource, the Sandusky River.

Working together with Chemistry professor, Thomas E. Taylor, Baker put together a proposal to Heidelberg’s administration requesting support for implementing a “River Labs” component in the college’s fall semester Introductory Biology course. President Terry Wickham saw value in the proposal and provided the Biology Department with $2,500 from an Esso Foundation grant the college had recently received. This funding enabled Baker and Taylor to purchase the necessary equipment and supplies to provide for an ambitious sequence of water sampling and analysis laboratory exercises.

Although that grant can be considered as the original seed money from which the National Center for Water Quality Research (NCWQR) eventually grew, it was actually not the origin of scientific research into water resource issues at Heidelberg College.

Ira T. Wilson came to Heidelberg in 1923 from Indiana University with a freshly minted Ph.D. in Zoology. In Teaching the Natural Sciences at Heidelberg College, a history of Biology and Geology at the College, George Barlow writes that, “Dr. Wilson was Heidelberg’s first scholar-teacher in that he was able to balance the severe demands of heavy teaching loads with research and scientific writing.”
Severe demands, indeed. On his arrival at Heidelberg, the Department of Biology was offering 9 courses in biology. Fifteen years later, the curriculum had increased to 21 courses with Wilson, who was soon chairing the Department, bearing the brunt of the load while being assisted by a shifting array of full and part-time educators. Even so, during the 28 years of his tenure at Heidelberg (ended by his untimely death at age 52), Wilson spent many summers studying the chemical and biological properties of sediments in a set of lakes in Indiana, Michigan and Ohio. A 1938 contract with the Ohio Division of Conservation to study bottom deposits in Sandusky Bay referred to Wilson as “the only scientist in the middle west who has been making detailed studies of lake bottom deposits.”

At the time of his death in 1951, Ira’s close friend and protégé, Arthur G. McQuate, was working on completing his Ph.D. through Ohio State University while teaching biology full-time at Heidelberg. Like his mentor, McQuate was drawn to aquatic studies, completing his doctorate (when he was 58) on the phytoplankton of Sandusky Bay. McQuate was to chair the Department of Biology until his retirement in 1966. It is no coincidence that this was also David Baker’s first year as a member of the Department.

But Baker was not brought on staff to carry forward Wilson and McQuate’s tradition of aquatic studies. His Ph.D. and subsequent research had been in plant physiology and besides a summer at OSU’s Stone Laboratory field station, an undergraduate stream study, and an abiding love of fishing, Heidelberg had no cause to suspect where his interests would shortly turn. Rather, David was viewed as the almost perfect solution for the crucial question of who was to shoulder McQuate’s heavy teaching load—especially his highly popular Principles of Biology (BIO 101) course taken by both majors and non-majors.

In his remembrance of McQuate on his death in 1973, Dr. Howard Hintz (the Department’s Field Biologist/Ecologist, 1951-85) wrote, “His great vitality in handling the last section of...[Biology 101 on a given day] was for many of us Dr. McQuate’s most amazing visible performance. With our small lecture room...we had to repeat the same lecture many times on the same day, and I can still picture ‘Mac’ in mid-afternoon giving his fourth or fifth lecture [on the same topic] but making it sound like the most important subject in the world.”

Dave Baker seemed the ideal candidate—direct from central casting—to fill the legendary teacher’s shoes. A well-published young researcher with several years teaching experience, he would be coming to Heidelberg with superb credentials as a scientist and educator. But at least as exciting to the College, Dave was still well-remembered from his standout years as an undergraduate. An honor student, member of the Tri-Beta biology honorary society, star miler on the track team, Student Council member and President of the junior class who had himself experienced McQuate’s introductory course—the loyal alum would surely address the Department’s long-term staffing needs following the renowned teacher’s retirement.

Well, yes and no.
At the recommendation of Dean Arthur Porter, President Wickham allocated $2,500 from an Esso Foundation general grant to Heidelberg, to Baker and Tom Taylor of the Chemistry Department (who left Heidelberg in 1968) for purchase of an oxygen meter, specific ion meter and various supplies required to implement the ‘River Labs’ component of the Biology 101 Laboratory experience. It’s useful to review the basic outline of the 3-week sequence as an early example of Baker’s creative approach to addressing scientific problems and the meticulous attention to the experimental design and quality control practices that were to become hallmarks of the Lab and a key to its long-term success.

Beginning with the fall semester of 1967, the laboratory component of BIO 101 was redesigned to consist of 11 exercises, with each faculty member of the Department contributing one or more exercises in their area of expertise. Baker’s ‘River Labs’ section consisted of a three-week sequence in which each student gained practical experience in monitoring phosphorus, Biochemical Oxygen Demand (BOD) and coliform bacteria within the Sandusky River. The easiest way to orchestrate such an undertaking would have been to bus each of the eight 24-student laboratory sections for a given week to the same location on the river where everyone would conduct the same measurements within a few meters of each other. Although this might introduce a student to the use of a particular piece of sampling equipment, it would not provide much useful information about water quality in the river beyond that one locale.

However, Baker took advantage of the three-week structure of the study—and of students’ willingness to take on a degree of independent responsibility in conducting the lab work—to develop an extensive data set with much greater potential for providing meaningful insights into the river’s ecology. Each of the eight (24-student) laboratory sections was divided into three groups, with each group further divided into two subgroups of 4 students in order to provide replicate analyses for quality control purposes. In the first week, each group within a lab was assigned one of three water quality parameters (phosphate concentration, BOD or fecal coliform) to analyze in samples from six sites along the Sandusky River. A total of 24 sites along a 90 mile stretch of the river bracketing sewage treatment sites in Bucyrus, Tiffin and Upper Sandusky were selected for study. Samples were collected by staff (often accompanied by lab assistants or students) who made 4 collection trips per week, with each trip visiting 12 stations.

Over the course of the three weeks, each group within a lab cycled through measurements of each of the three parameters. Thus, with 48 samples being analyzed per week (24 stations sampled twice per week), the three week exercise engendered 144 samples—six samples for each of the 24 stations. A “blind” replicate sample from one of the six stations for each lab section, provided additional quality control information. Already, Baker’s penchant for experimental designs that generate copious amounts of information (one of his nicknames is “Data Dave”) was proving problematic. In the second year of the new program, a fourth week had to be added to the River Labs sequence to provide time for students to analyze and compare the data within and between laboratory sections.

* Students had to come in on their own time to do the bacterial counts and conduct the final dissolved oxygen measurements for the 5-day BOD experiments.
Problematic but exceptionally fruitful. By the end of 1968, the River Labs had generated a significant amount of information on nearly 100 miles of the Sandusky River. As would become an oft-repeated pattern, the data suggested to Baker an idea for a research project that would extend Heidelberg’s riverine studies into a new area of investigation. Around this time, the Northwest Ohio Water Development Plan was being implemented by the Ohio Division of Natural Resources as a mechanism to improve summertime water quality in several area rivers. The thinking was that by developing a set of 37 multipurpose upland reservoirs that could be filled during rainy parts of the year, managers would have the means to “augment” water flow in rivers during low-flow periods of mid- to late-summer, thereby improving water quality by diluting pollutants entering the rivers from sewage treatment plants.

However, the extent to which such a flow-augmentation regimen might actually impact water quality within a river was unknown. Baker applied for a grant for $47,650 under the Federal Water Pollution Control Administration (the FWPCA was one of the forerunners of the EPA) to study the effects of flow-augmentation from the pump storage, up-ground Killdeer Reservoir that was being constructed as part of the Development Plan for the Sandusky River. The grant, received in December 1968, allowed for the creation of a small research laboratory in the basement of Laird Hall, the purchase of additional equipment, funds for hiring several part-time student helpers and the laboratory’s first full time employee, Heidelberg Chemistry graduate, Jack Kramer.

Thus, it is reasonable to date the origin of the “Water Lab” as an independently funded research facility to the 1969 initiation of year-round research on the “Sandusky River Project” and the beginning of Kramer’s remarkable 43 year employment as the second pivotal member, after Dr. Baker himself, of the team that built the lab literally from the ground up—from a single 600 sq. ft. room in the basement of Laird Hall to its present location occupying the entire top floor of Gillmor Hall.

Over the decades since, the Lab under Dr. Baker and his successors has managed to attract and fully engage the talents of an extraordinary corps of technicians and scientists in pursuing its expanding research agenda. The productive interplay between members of this diverse community of investigators over the years—together with a smattering of a few less productive interactions (to be found in any group of high-energy, strongly opinioned professionals)—is central to the lab’s story. But the Baker-Kramer dyad merits special attention here because it pertains to the question that has so often puzzled researchers visiting from large, well-staffed Research I institutions across the country:

How it is that a world-class water research facility came to exist—and thrive—at Heidelberg College, a small liberal arts institution without even a Master’s-level graduate program to provide a steady supply of workers to undertake the arduous task of collecting and analyzing the masses of data that is the raw fuel of any successful laboratory?

*Laird Hall built in 1913 housed the Department of Biology until it relocated to the newly constructed Gillmor Hall in 2006. The renovated Laird Hall, renamed Adams Hall, opened as the home of the School of Business in 2010.
†Thus the Lab predates the first Earth Day (Apr 22, 1970) and the creation of the EPA (Dec 2, 1970) by over a year.
In his comments on Kramer’s retirement in 2012, Dr. Baker neatly summarized Jack’s long-term importance to the lab. “Our laboratory runs like a well-oiled machine. Jack built that machine, keeps it running, and helps keep it growing.” He then ticked off an abbreviated list of critical “trades” that this Jack-of-all-trades had brought to his work: Jack-the-plumber, electrician, carpenter, welder, front loader operator, machinist, photographer and film developer, analytical chemist, equipment builder and repairman, laboratory architect, computer programmer, data management system developer, grant proposal consultant and teacher.

Dave was not just using a figure of speech in claiming that “Jack built that machine.” Many of the Lab’s early successes were founded on field sampling technology, analytical chemistry and automated data transfer systems that he designed, built and implemented years before similar commercially produced systems were first employed at other research facilities.

More than one member of the Lab, commenting on their working relationship, has referred to Dave and Jack “like an old married couple” who would bicker back and forth over the feasibility of some idea of Dave’s for a new project until they had co-arrived at a workable solution. Each knew the other’s strengths and weaknesses and their disagreements over what might be vs. what actually could be achieved were often strident and almost always productive.

“Baker was such a dreamer, you’d want to whack him” said one long-time member of the Lab, “while Jack’s perspective was so practical it was sometimes like throwing a wet blanket on Baker’s creativity.” And yet the marriage worked. Dave was smart enough to recognize and channel Jack’s diverse talents and Jack was sharp enough to see where Dave wanted to go and inventive enough to make it happen.

Staff members soon learned to recognize the danger signs of another intellectual storm in the making: Watch out if, after a morning pouring over the latest data, Dave came into the Lab with a coffee cup and a certain twinkle in the eye. And as Jack looked up warily from the litter of whatever piece of gear he was disassembling, Dave would begin, “Now wouldn’t it be interesting if…”

The Sandusky River Project and the Summer Storms of 1969

Baker and crew could hardly wait for the summer’s research on the flow augmentation study to begin. Kramer’s full-time employment was to begin several weeks after his graduation in May and completing the Sandusky River Project team would be professors Ed Ashworth (Geology), Ray Wise (Physics) and John Jakobs (Computer Center)—none of whom knew anything about nutrient sampling—along with several undergraduate assistants who had been through the Biology 101 River Labs sequence. This first year of the work was to be the control study while Killdeer Reservoir was under construction. The researchers expected to document increasing concentrations of pollutants as water flow in the Sandusky diminished to its typical trickle over the course of the summer. Then, in succeeding years, they would monitor the extent to which late summer releases of water from the new reservoir would dilute the pollutants.
At least, that was the expectation. Certainly, the Northwest Ohio Water Development Plan’s Flow Augmentation program had been designed to mitigate anticipated pollutant concentration events. Things, however, did not go exactly as planned, as Baker recalled in his March 1990 Introduction to the Lab’s first Annual Report. Reflecting back on the preceding two decades, Baker thought enough of that first summer’s work to devote a paragraph describing how things went…

All summer long, Heidelberg’s staff and students were conducting daily visits to 20 bridges along the Sandusky River and its tributaries, collecting grab samples and returning them to the new water chemistry lab where they were analyzed for total and soluble phosphorus, suspended sediments and various metals. The streams remained high and turbid most of the summer, and the low flows that staff and students were looking for never came. It was a bad summer for flow augmentation research.”

In fact the summer of 1969 was notable for its record-setting storms, especially around Independence Day. For a sense of just how “bad” the summer was for flow augmentation research, consider this quote taken from a USGS report on the resultant flooding:

The storm of July 4-5, 1969 in north-central Ohio was an unprecedented event; never before has such intense and widespread precipitation been recorded for a summer storm in Ohio (U.S. Dept. of Commerce, 1969). More than 14 inches of rainfall in less than 24 hours were observed at several places. In areal extent more than 4 inches of rainfall occurred on about 6,000 square miles … Peak discharges at five of the 40 [sampled] sites were four times as large as the discharge of the 50-year flood and the peak discharge for 17 sites was more than twice as large as that of the 50-year flood.

Although the Sandusky River basin did not receive the extreme volume of flood waters experienced by rivers in north-central Ohio, it was more than enough to upend any plans for monitoring increasing pollutant concentrations in the river during mid-to-late summer low flow conditions—fortunately so, as it turned out. In spite of often difficult sampling circumstances, the research team carried through with its planned rigorous summer research program involving “grab sample” (bucket on a rope) collection methods, manual analysis of phosphorus, sediments, metals and bacteria, and then recording and analyzing the data by hand.

But on reviewing the data, the researchers found something quite unexpected. Far from diluting phosphorus concentrations in the river, all those storm events translated into massive amounts of phosphorus moving down river. At the time it was thought that most phosphorus came from municipal and industrial sources and that agriculture was not generally an important source of the nutrient. In 1967 the FWPCA had conducted a limited one-year study examining phosphorus inputs into Lake Erie. Its widely accepted findings suggested that 72% of phosphorus loadings into the Lake came from urban sources while only 17% came from rural runoff.

The Lab’s findings, however, suggested almost the polar opposite of those results. In a newspaper interview addressing the Lab’s 1969 study, Baker observed that while the FWPCA’s assessment might have relevance for Lake Erie as a whole, agriculture-dominated river systems like the Sandusky experience a very different set of circumstances than those encountered in urban-dominated systems like Cleveland’s Cuyahoga. “In one 36-hour period, more phosphorus went past Tindall Bridge [on the Sandusky near Fremont] than what Tiffin puts in during a year,” he noted.
It took a few years for the wider scientific community to understand the significance (and accept the reality) of the Lab’s discovery that the movement of phosphorus through rivers in agriculture-dominated watersheds coincides with storm events and the consequent displacement of phosphorus from farmed fields. However, this one finding was to become the cornerstone of the Lab’s national reputation and the seed from which was to grow one of its most influential endeavors, the Heidelberg Tributary Loading Program.

~A rather lengthy but hopefully useful digression~

*A Primer on Phosphorus, HNABs, Federal Law, International Agreements and Lake Erie*

Why phosphorus? What is it about phosphorus, of all elements the lab has studied, that first drew the attention of the nation’s scientists, public media and governmental regulatory agencies to the work going on at Heidelberg? The short answer is that while phosphorus is a necessary component in the biochemistry of all living organisms, it does not occur in great abundance in unimpacted freshwater ecosystems.

The keyword here is “unimpacted,” meaning unaffected by human activities. Within unimpacted freshwater bodies, excessive growth of various types of algae is typically “limited” by the availability of phosphorus in a usable form. (The chemistry of saltwater differs; in unimpacted marine ecosystems it’s more often nitrogen that limits algal growth.) Of course, the problem is that, worldwide, few freshwater systems have escaped significant inputs of human-generated phosphorus from ineffective sewage treatment systems and fertilizer-enriched runoff from rural and suburban landscapes. And when algae are no longer limited by the availability of this critical nutrient, their resultant explosive growth creates what is referred to as an “algal bloom” (Figure 1).

![Figure 1. Images by NOAA and Sea Grant. Left: Satellite image of 2011 algal bloom in Lake Erie. Top right: Bloom severity index 2002-2016. Bottom right Close-up views of a severe bloom. Algal blooms cause problems in a variety of ways, especially in lakes and larger rivers. Dense concentrations of algae greatly reduce water clarity, blocking sunlight from reaching rooted aquatic plants and interfering with the foraging and reproductive behaviors of aquatic animals. In severe blooms, once-clear waters are turned into an unappealing green soup, strongly](image-url)
impacting tourism and fishing industries and depressing the value of shoreline properties. Worse, by mid-summer massive algal die-offs can lead to hypoxic (low-oxygen) waters which in turn result in fish kills and shorelines strewn with masses of rotting scum.⁹

It’s important to note that the word “algae” is a catchall term for a wide array of taxonomically unrelated organisms. For example, in the late 1960’s many of the worst so-called algal problems in the Great Lakes were associated with two quite different groups of organisms: filament-forming members of the genus Cladophora, a type of green algae, and various members of several genera of Cyanobacteria. Commonly referred to as blue-green algae, cyanobacters are actually much more closely related to bacteria than to the green algae. Although Cladophora and other green algae can still cause headaches, during the first two decades of the 21st Century the Great Lakes—like many other lakes and impoundments throughout the Northeast—have experienced increasingly severe problems with Cyanobacteria.

Under certain environmental conditions, some 40 species of Cyanobacteria (especially those belonging to the genera Dolicospermum (formerly Anabaena), Aphanizomenon, Microcystis and Planktothrix) produce a variety of nerve-, liver- and skin-damaging compounds collectively known as cyanotoxins. Algal blooms of toxin-producing cyanobacters are commonly referred to as Hazardous and Nuisance Algal Blooms (HNABs) and tend to occur in warm, shallow lake waters high in phosphorus concentration. The Western Basin of Lake Erie, with an average depth of just 7.4 m (24 ft) and heavy nutrient inputs from the Maumee River has been especially prone to late summer HNABs in recent years.

In August 2014, an HNAB in the vicinity of Toledo’s water intake crib in Lake Erie overwhelmed the city’s water treatment plants leading to a three-day ban on using city tap water for drinking and washing. However, late-summer HNABs of similar or larger size had plagued the Western Basin for at least a decade preceding the Toledo crisis. The Western Basin concentration of microcystin (the most common cyanotoxin) during the 2011 bloom was 50 times higher than the World Health Organization’s limit for safe body contact, and 1,200 times higher than the limit for safe drinking water. Also, when dense masses of algae die, fall to the bottom of the lake and are broken down by aerobic (oxygen-consuming) bacteria, hypoxic “dead zones” are created in deeper waters. Lake Erie’s Central Basin has experienced dead zones averaging 4,500 km² since the early 2000s, with the largest event of 8,800 km² occurring in 2012 following the record algal bloom of 2011.¹⁰

And yet in 1987, the best scientific evidence led Lake Erie authority Charles Herdendorf, to write, “In response to lower phosphorus concentrations basin-wide, blooms of planktonic blue-green algae (e.g. Microcystis, Aphanizomenon, and Anabaena) in western Lake Erie, and massive growths of attached filamentous green algae (e.g. Cladophora) which were so prevalent in the mid-1960s decreased in intensity and number during the 1970s, and no basin-wide blooms have been reported in recent years.”¹¹ So how to explain the Lake’s seeming retrenchment, by the 2000s, from Herdendorf’s further upbeat assessment that “evidence for improvement is beginning to mount and it is becoming obvious to scientists, fishermen, and shoreline dwellers alike that Lake Erie is recovering from nutrient overload…”?
Did something happen that sent phosphorus concentrations soaring back to levels not seen since the media declared Lake Erie “dead” in the late sixties? The answer rather depends on what’s included in the catchall term, “phosphorus.”

When European explorers first encountered the Great Lakes in the 16th Century, most of the region was heavily forested and streams and rivers ran clear, cold and seldom flooded. Extensive wetlands and wooded banks stabilized shorelines, slowing erosion and nutrient runoff into waterways from adjacent lands. Over the next 150 years, pollution problems were generally restricted to areas of heavy logging, agriculture and nascent urbanization and did not trigger widespread public concern, the prevailing view being that the Lakes were too large to be seriously impacted by human activities. However, when some 15% of Chicago’s population perished during the great cholera and typhoid epidemics of 1885-1887, the health aspects of polluted lake waters could no longer be ignored.12

The Federal Refuse Act of 1899 and the Federal Water Pollution Control Act (1948) had been designed to address water pollution issues but neither law had the regulatory teeth to be strongly enforced. Meaningful anti-pollution regulations had to wait until widespread public outcry led to the passage of the Federal Water Pollution Control Act Amendments, more commonly known as the Clean Water Act (CWA) in 1972. This was also the year that Canada and the United States signed the Great Lakes Water Quality Agreement (GLWQA) with the stated purpose of cooperating to “…restore and maintain the chemical, physical, and biological integrity of the Waters of the Great Lakes.”13

The GLWQA was amended in 1983, 1987 and 2012, with the 2012 modification restructuring the Agreement into 13 Articles (describing the general objectives and responsibilities of the two countries) and 10 issue-specific Annexes. The history of the Agreement from its inception in 1972 to the present day reflects the shifting environmental and political realities impacting efforts to manage Lake Erie’s water quality challenges over the past five decades. To a large degree, those realities have framed the arena within which the NCWQR has conducted its research. Appendix B offers a detailed overview of the Great Lakes Water Quality Agreement and its most important Amendments.

GLWQA 2012 “Annex 4: Nutrients” focused attention on the environmental importance of phosphorus through a set of Key Commitments,14 the first two of which were to:

- by 2016, develop binational substance objectives for phosphorus concentrations, loading targets, and loading allocations for Lake Erie.
- by 2018, develop binational phosphorus reduction strategies and domestic action plans to meet the objectives for phosphorus concentrations and loading targets in Lake Erie.

In February 2016 the U.S. and Canada formally adopted three phosphorus loading targets for Lake Erie’s western and central basins15 (with the finalized U.S. Action Plan for implementing nutrient reductions under Annex 4 released in February 2018):
• To minimize the extent of hypoxic zones in the waters of the central basin of Lake Erie: a 40 percent reduction in total phosphorus (TP) entering the western and central basins of Lake Erie—from the United States and from Canada—to achieve an annual load of 6,000 metric tons to the central basin. This amounts to a reduction from the United States and Canada of 3,316 metric tons and 212 metric tons respectively [relative to a 2008 baseline].

• To maintain algal species consistent with healthy aquatic ecosystems in the nearshore waters of the western and central basins of Lake Erie: a 40 percent reduction in spring TP and soluble reactive phosphorus (SRP) loads from the following watersheds where algae is a localized problem: in Canada, Thames River and Leamington tributaries; and in the United States, Maumee River, River Raisin, Portage River, Toussaint Creek, Sandusky River and Huron River (Ohio).

• To maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the waters of the western basin of Lake Erie: a 40 percent reduction in spring TP and SRP loads from the Maumee River in the United States. Using 2008 as the baseline, this equates to a spring (March-July) load of 860 metric tons TP and 186 metric tons SRP.

Two points worth noting in the above Annex 4 targets: the targets call for reductions in phosphorus “loads” i.e., reductions in the amounts of phosphorus entering the western and central basins rather than focusing on the concentration of the nutrient in lake waters (as in the past), and the 40% reduction targets of the second and third bullets refer to both total phosphorus (TP) and soluble reactive phosphorus (SRP).

Standards based on phosphorus loadings in rivers emptying into the lake were developed because it was discovered that concentrations of the nutrient vary considerably both within a given location over time and between locations, making it difficult to use measurements of phosphorus concentrations in lake waters as a tool for monitoring the effectiveness of phosphorous reduction programs.

Unfortunately, the terminology for the various forms of environmentally relevant phosphorus can be confusing. Of central importance, it should be understood that although much of the discussion of nutrient problems within freshwater systems has focused on “phosphorus,” pure, elemental phosphorus (P) is not commonly encountered in nature. Rather, the element is usually attached to several oxygen atoms forming a phosphate molecule (PO₄). A phosphate bound to a carbon-containing molecule (such as in the tissues of living organisms or sewage) is referred to as an organic phosphate. When it is not so attached it is called inorganic phosphate.

While animals can make use of both organic and inorganic phosphates, plants can only utilize the inorganic form. Both organic and inorganic phosphates can be found dissolved in water or attached to clay or other particles and these “particulate phosphates” (PP) may be either suspended in the water column or embedded in sediments on the bottom of a water body. During the cycling of phosphorus in aquatic systems, inorganic phosphates are absorbed by plants and algae and processed into organic phosphates as part of their tissues. Animals obtain organic
phosphates by feeding on plants, algae or other animals. Finally, organic phosphates in animal wastes and dead organisms are converted by bacteria back into inorganic phosphates, completing the cycle.

There are two forms of inorganic phosphates: orthophosphates and polyphosphates (or condensed phosphates). Orthophosphates are lone phosphate (PO₄) molecules. They are also known as reactive phosphates because they are the form of phosphates that react with the diagnostic chemicals used in laboratory tests checking for the presence of phosphates in a water sample. Polyphosphates are attached to salts and/or metals and are commonly used as food additives. Unstable in water, they eventually convert into orthophosphates.

Since the 1970’s, laboratories monitoring nutrients in streams, rivers and lakes throughout the nation have relied on “total phosphorus” (TP), which is a measure of all forms of phosphate containing compounds—organic, inorganic, dissolved, particulate—as their primary tool for tracking changes in phosphorus within freshwater ecosystems. However with the resurgence of major algal blooms in Lake Erie and elsewhere in the 1990’s, it became clear (in large part due to long-term studies by the NCWQR) that the measurement of soluble reactive phosphorus (SRP or DRP*)—orthophosphates that are dissolved in the water rather than attached to particles—is for many purposes a superior tool for monitoring the environmental health of aquatic ecosystems.¹⁶ As noted above, the GLWQA’s finalized U.S. Action Plan for implementing nutrient reductions under Annex 4 calls for 40% reductions in both TP and SRP.

NB: In the following discussion, and throughout the rest of this history, references to “phosphorus” are to be understood as shorthand for “phosphorus-containing compounds” (primarily phosphates).

In a 2017 presentation, Dave Baker discussed the importance of distinguishing between dissolved and particulate phosphorus-containing compounds in monitoring the ecological health of aquatic systems.¹⁷ While Total Phosphorus measures all forms of phosphorus that are either dissolved in the water or bound to particles, the EPA’s standard for dissolved (= soluble) phosphorus includes only those forms that can pass through a filter with 0.45 micron pores. It’s especially important to note that the two categories of phosphorus are not equally “bioavailable,” usable by plants and algae. Numerous studies have shown that while the bioavailability of particulate phosphorus is only about 25%, that of dissolved phosphorus is almost 100%.

The relative abundance of dissolved and particulate phosphorus in a given tributary to Lake Erie has been found to be directly tied to land-use patterns within the tributary’s watershed. As indicated in the Figure 2, the watershed of the Cuyahoga River, which passes through Cuyahoga Valley National Park and Cleveland, is dominated by forested and urban land use,

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*Soluble Reactive Phosphorus (SRP) is equivalently referred to as Dissolved Reactive Phosphorus (DRP), the term often used in reports and presentations produced by the NCWQR. Again, note that although both terms refer to “phosphorus,” what’s really being referred to here is dissolved phosphate.
Figure 2. Land use patterns within four North Ohio watersheds. The Maumee and Portage Rivers empty into Lake Erie’s Western Basin, the Sandusky and Cuyahoga Rivers into its Central Basin. (NCWQR illustrations archive)

while row crop agriculture dominates land use in Ohio tributaries draining into Lake Erie’s Western Basin and Sandusky Bay.

Formerly, the great majority of phosphorus entering the Cuyahoga came from point sources such as wastewater treatment facilities and industries; it consists primarily of highly bioavailable dissolved reactive phosphorus (DRP). However, because of the implementation of advanced phosphorus removal programs at sewage treatment plants within the watershed, and relatively low concentrations of bioavailable phosphorus within its forested soils, in recent years the Cuyahoga’s DRP levels have been much lower than those seen in Northern Ohio rivers draining agriculture-dominated watersheds. In contrast to the Cuyahoga, the majority of the phosphorus entering the agriculture-dominated Maumee, Portage and Sandusky Rivers is low-bioavailability particulate phosphorus (PP), the result of extensive nonpoint inputs from fertilized fields.

A crucial point is that in recent times the latter three rivers have each far exceeded the Cuyahoga in the total amount of phosphorus transported into the lake. In fact, for 2008 (the baseline year against which GLWQA Annex 4 nutrient reduction targets were established) the Maumee and Sandusky recorded the highest two total phosphate (TP) loadings (3,812 and 1,105 metric tons, respectively) of all rivers in the entire Great Lakes watershed. Together, they contributed over 50% of all phosphorus entering Lake Erie. For the 2013 water year (October 1, 2012 to September 30, 2013), an estimated 89.6% of the total phosphorus exported from the Maumee and 94.7% from the Sandusky came from nonpoint (chiefly agricultural) sources.

Figure 3 shows that some 80% of the phosphorus in that runoff was particulate and 20% dissolved. However, as has been noted, while essentially all dissolved phosphorus is bioavailable to algae, only 25% of particulate phosphorus is bioavailable. Also, the furthest left and right-hand bars of the figure point out that while virtually all of the dissolved phosphorus is suspended within the water column, an unknown component of particulate phosphorus settles out of the
Thus, considering both the large amount of poorly bioavailable particulate phosphorus and the small amount of highly bioavailable dissolved phosphorus, the NCWQR’s data suggest that about 40% of the total phosphorus in nonpoint runoff entering Lake Erie from the Maumee and Sandusky Rivers would be readily available to algae.

In 1978, the GLWQA set a target load of 11,000 metric tons of total phosphorus/year for Lake Erie. Figure 4 shows that management actions taken by the U.S. and Canada led to that target being first met in 1981, and generally remaining below it thereafter.
The great majority of this decline from peak concentrations in the late 1960’s—some 84%—was the result of emphases initiated in the mid 1970’s on reducing phosphorus inputs from point sources. The 1983 GLWQA Amendments called for an additional 2,000 metric tons reduction with emphasis on reducing nonpoint sources through conservation tillage (especially no-till) practices. Subsequently, however, nonpoint source inputs were only reduced by about 13% due in part to increased annual discharges (flow) into tributaries draining into the Lake.

By the early 1990’s, algal and cyanobacteria concentrations within Lake Erie had dropped to the point where it seemed that problematic algal blooms were a thing of the past and environmentalists might set their sights on other pollution issues. However, as is illustrated in Figure 5, by the end of that decade it was clear the lake was experiencing significant re-eutrophication with a consequent resurgence in algal biomass.

Although it has been demonstrated that observed increases in algae within the lake in the 1990’s and 2000’s were not correlated with comparable changes in total phosphorus, it is useful to examine changes in particulate and dissolved phosphorus, the two components of TP, during this period. The two plots presented in Figure 6 for the Maumee River, the largest contributor of bioavailable phosphorus to the Western Basin of Lake Erie, are especially informative. Long-term trends in particulate and dissolved phosphorus export from the Maumee into the Western Basin indicate that while particulate phosphorus showed no consistent pattern from the 1990’s onward, the loading of dissolved reactive phosphorus increased markedly during this period of re-eutrophication. Remembering that DRP (SRP in Annex 4 terminology) is fully bioavailable, there is little doubt that the striking increase in the Maumee’s export of dissolved phosphorus

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*Inferences based on comparing the graphs on the left and right sides of Figure 5 should be tempered by the fact that the data for the 1970-1986 Western Basin data was based on a small number of open lake samples near the mouth of the Detroit River while the 1996-2006 data was based on numerous nearshore samples. In similar fashion, the 1970-1986 Central Basin data was based on a small number of open lake samples while the 1996-2006 data was based on multiple nearshore samples.
underlies the prevalence of the western basin’s algal blooms in recent times. Although long-term monitoring data are unavailable for definitive assessments, massive algal blooms in other HNAB-troubled bodies of water such Ohio’s Grand Lake Saint Marys seem likely to have been accompanied by jumps in DRP input.

Figure 6. Trends in spring (March-July) PP and DRP concentrations in the Maumee River, 1975-2016. (NCWQR illustrations archive)

The widespread increase in DRP concentrations within rivers of agriculture-dominated water basins was largely an unintended consequence of the extensive adoption during the 1990’s of conservation tillage practices—especially reduced and no-till methods—throughout the Lake Erie watershed. Beginning in the 1980’s, such pre-planting field treatments were strongly advocated as a mechanism for reducing soil erosion and building the soil’s physical and biological structure. Unlike conventional moldboard plowing that clears fields of vegetative growth by inverting the soil, low- and no-till practices use specialized equipment allowing the planting of crop seed within fields that remain protected from erosion by residue (remnants) from the previously harvested crop. Although conservation tillage methods have proven effective in reducing soil erosion (and consequent particulate phosphorus export) into area streams and rivers, they have also been central to the observed spike in DRP (Figure 7).

Figure 7. DRP in runoff from two wheat fields in Oklahoma that were both tilled until 1984 when one was converted to no-tillage methods. (Kleinman, P.J.A., et al. 2011)
The increase in DRP loading into area streams and rivers with no-till practices is due to a set of interacting factors. Broadcasting of phosphate-enriched fertilizers atop residue-stabilized soil has led to the buildup of a phosphorus gradient within the uppermost layers of no-till treated fields. This “phosphorus stratification,” with high concentrations of the nutrient in the top few centimeters of soil, has been further strengthened by the breakdown of crop residues at the soil surface. Storm events occurring before incorporation of phosphorus into the soils then results in “acute” phosphorus losses—enhanced movement of dissolved phosphorus from fields into neighboring waterways.

![Figure 8. Lake Maumee at the southern edge of the Laurentian ice sheet. Today’s locations of the Great Lakes are outlined in black. Note how Lake Maumee extends west of modern Lake Erie. (Public Domain, https://commons.wikimedia.org/w/index.php?curid=1162512)](image)

The situation is compounded in northwestern Ohio, and especially in the Maumee River watershed, by the late-Pleistocene geological history of the area. Some 14,000 years ago at the end of the last ice age, Lake Maumee, the ancestor to present-day Lake Erie, formed at the southern edge of the Laurentide ice sheet (Figure 8). The lake’s initial outlet was near what is today Fort Wayne, Indiana and over the next several thousand years a clayey lake bottom developed throughout the area that was to eventually become some of the most productive agricultural lands in the nation. These clay-dense soils, however, have required extensive tiling (networks of subsurface drainage conduits) to clear standing water from the land for farming.

The top 4-5 cm of agricultural surface soil is known as the “zone of interaction” and the buildup of large amounts of phosphorus in this zone due to many years of broadcast fertilization and crop residue decomposition is referred to as “legacy phosphorus.” During storm events, the zone of interaction acts like a leaky sponge with significant amounts of dissolved phosphorus exiting it with surface runoff. Acute losses of phosphorus are especially severe when rainstorms of sufficient size to generate surface runoff occur shortly after broadcast application of fertilizers (or manures). Since most P-fertilizers are highly soluble, runoff-inducing rainstorms that occur
before the fertilizers have reacted with soil chemicals result in extremely high DRP concentrations, as shown in Figure 9. This is the basis for laws and recommendations banning fertilizer applications prior to predicted runoff-inducing rainfall.

![Figure 9. Stream flow (top) and DRP concentration (bottom) in Honey Creek, Sep-Dec 2011.](NCWQR illustrations archive)

It has been discovered that no-till practices are accompanied by the abundant formation of “macropores”—fissures in the soil leading down through the zone of interaction. The release of DRP through macropores into subsurface tiles and offsite receiving waters represents a large component of “chronic” (long-term) loss of legacy phosphorus from the soil. Both acute and chronic losses involve surface runoff and macropore-tile routes from field to river. Although acute losses of dissolved phosphorus due the surface runoff during storm events lead to much higher spikes in tributary DRP concentrations than chronic losses at these times, NCWQR data has led the Lab’s researchers to conclude that chronic losses of legacy phosphorus from the zone of interaction represents a larger proportion of the DRP export from agricultural fields which has been primarily responsible for the recent re-eutrophication Lake Erie.

As a result, Baker has observed that action plans for reducing algal blooms in Lake Erie should place much greater emphasis on reducing dissolved phosphorus loading to Lake Erie than on particulate phosphorus reductions. Interestingly, this has put the Lab somewhat at odds with the Annex 4 recommendations adopted in 2016 under the GLWQA. As noted above, the finalized U.S. Action Plan released in February 2018 calls for 40% reductions of both total phosphorus (TP) and soluble reactive phosphorus (SRP or DRP) from 2008 baseline concentrations “to maintain algal species consistent with healthy aquatic ecosystems in the nearshore waters of the western and central basins of Lake Erie…[and] to maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the waters of the western basin of Lake Erie.”
A 40% reduction in TP translates into a 40% reduction in both particulate and dissolved phosphorus. However, NCWQR researchers question the advisability of a 40% reduction in particulate phosphorus loading as a significant component of efforts to control harmful algal blooms in Lake Erie. Rather, they argue, far more effort should be placed on reducing dissolved phosphorus loading and less on reducing particulate phosphorus loading through additional erosion control programs since soil erosion no longer appears to be a major contributor to the export of bioavailable phosphorus into Lake Erie. This topic is explored in greater detail in Chapter 5, The NCWQR and collaborators address the re-eutrophication of Lake Erie.
Chapter 2. The Seventies

The River Studies Laboratory

The Lab’s studies over the next several years reinforced the importance of exploring the impact of storm events on the movement of pollutants through agriculture-dominated watersheds. At the time it was widely believed that the great majority of phosphorus inputs into Lake Erie came from municipalities and industries, with agricultural inputs of only minor concern. However, the unexpected pulses of phosphorus and other pollutants observed during high water periods of the 1969 Flow Augmentation Study convinced Baker and Kramer that, at least for the Sandusky River, this was too simplistic a view.

It was important to more accurately determine the relative contributions of point and nonpoint (diffuse, as it was then often called) terrestrial sources of the phosphorus in riverine waters, a task that would occupy much of the staff’s time and energies from this time forward. Collaboration with other organizations was to prove helpful and often necessary in these efforts. In 1972, workers at Tiffin’s sewage treatment plant collected water samples every 2 hours in a study of diurnal fluctuation of phosphorus inputs into the Sandusky River. Emblematic of Baker’s commitment to incorporating real-world research problems into Heidelberg’s undergraduate science curricula, students analyzed these data in a laboratory course entitled Research in Aquatic Ecosystems.

At the 16th International Association for Great Lakes Research (IAGLR) Conference,¹ Baker reported that in 1973 (a high rainfall year) a maximum of just 13% of total phosphorus entering Lake Erie from the Sandusky River Basin came from point sources while more than three-quarters of phosphorus loading came from diffuse sources such as agricultural run-off, drainage tile effluent, stream bank erosion and other non-point inputs. And yet virtually all federal and state pollution control efforts at this time were focused on municipal phosphorus management.

As a salient example of this, the Ohio EPA had recently given all urban areas in the state with sewage flows greater than 1 million gallons/day until the end of 1973 to reduce effluent concentrations of phosphorus to 1 mg/liter, an expensive, unfunded requirement. With the support of State Representative Paul Gillmor and Tiffin Councilman Jim Wolf, Baker developed a novel proposal to OEPA for a 1-year waiver of the phosphorus removal program for Bucyrus, Upper Sandusky and Tiffin. The money saved would fund a 2-year Heidelberg study comparing urban and agricultural sources of phosphorus loading to the Sandusky River.

Perhaps unsurprisingly, OEPA said no. (USEPA had also voiced its disapproval, fearing the precedent of municipalities attempting to negotiate their way around its regulations.) But intriguingly, Jim Diebold, a reporter for the Tiffin Advertiser-Tribune, wrote an article on the situation after which OEPA reversed its decision and did grant the three towns the requested one-year phosphorus reduction waiver. More than an illustration of Baker’s innovativeness in securing funds for the Lab and the diverse factors at play in how government funds for research get distributed, the project represented a significant turning point in the laboratory’s history.
The reallocated funds of $41,625 from the three cities (along with a 2-year grant of $32,000 from the Soap and Detergent Association) supported the lab’s purchase of automatic samplers—freeing staff from having to manually collect water from the various sampling sites along the river—and of laboratory automation equipment for more rapid sample analysis. With the resultant, almost exponential increase in sampling intensity, Baker and Kramer were able to document diurnal, weekly and seasonal patterns in phosphorus, nitrogen and sediment transport within the Sandusky that were simply unavailable for any other river in the country. The newly named Heidelberg Tributary Loading Program (HTLP, Figure 1) began generating the type of detailed, long-term data that were widely understood to be necessary for developing effective management strategies in addressing Lake Erie’s pollution problems. No other research entity—governmental, university or private—was producing anything like the Lab’s quantity and quality of water quality data. The International Joint Commission, the USEPA and the U.S. Army Corp of Engineers took notice of the activity and of insights coming out of the small college’s research unit.

Under the Clean Water Act of 1972, Congress handed the task of cleaning up Lake Erie to the Corp of Engineers. In 1974-1975, the Corp awarded Heidelberg’s Lab three grants in connection with Phase I of its Lake Erie Wastewater Management Study (LEWMS) to develop a Mass Balance study for determining the relative contributions of point and nonpoint sources of phosphorus inputs into the Sandusky, Maumee, Portage and Huron Rivers. The HTLP’s Mass Balance/Whole Watershed approach to estimating the proportion of nonpoint sources of phosphorus (and other substances) within a river is illustrated in Figure 1. The method assumes

![Figure 1. The HTLP provides the necessary data for conducting a Mass Balance study to determine the relative contributions of point and nonpoint sources of a nutrient within a watershed. (NCWQR illustrations archive)](image)

that since mass can be neither created nor destroyed, a known amount of matter entering a riverine system should equal (mass balance) the amount stored within the system plus the amount exiting the system. As briefly summarized in the figure, subtracting the amount of phosphorus entering a
watershed’s streams and rivers from point sources (like wastewater treatment plant and industrial effluent discharges) from the total phosphorus exiting the watershed near the mouth of the river, provides an estimate of nonpoint sources of phosphorus due to runoff from agricultural and other broad landscapes.

The accuracy of the procedure depends heavily on the quality of data used to estimate point source loadings into, and export of phosphorus out of, the river system. Under the National Pollutant Discharge Elimination System (NPDES) established by Section 402 of the Clean Water Act in 1972, publicly owned treatment works (i.e., sewage treatment plants) and industrial sources were required to report the amounts of pollutants in their wastewater effluents. (In 1987, the program was expanded to include municipal and industrial stormwater discharges.) These publicly available data provided the best available estimates of point source loadings into river system.

At the same time, the intensive sampling regime established under the River Lab’s Tributary Loading Program presented a variety of options for interpreting the export data. For example, when synched with stream flow data provided by the U.S. Geological Survey, the Lab’s automated samplers allowed Baker and Kramer to explore the impact of storm events on the movement of phosphorus off a watershed’s landscape and into tributaries feeding western Lake Erie. The process is complicated by a number of factors that are difficult to quantify such as loadings from non-NPDES point sources and the conditions under which phosphorus moves into and out of “storage” in bottom sediments of streams and rivers. Nonetheless, the HTLP was soon recognized to be creating one of the most reliable and useful water quality data sets for any set of river systems in the nation. With the Lab’s expanding focus on an additional set of rivers came a name change from the Sandusky River Project to the River Studies Laboratory in 1974.

While David Baker’s work was gaining widespread recognition and bringing thousands of dollars in support of his research to Heidelberg, his role as an educator within the College was necessarily shifting. David had been brought on staff in 1966 to replace retiring teaching phenomenon, A.G. McQuate, in the Biology Department. By 1968, however, it was clear that the River Labs component of his Introductory Biology course was consuming much of his time. By 1972, his work on the Sandusky River Project required the Department to bring in part-time adjunct professors to teach his courses as David’s responsibilities directing the growing Lab obviated, first, his teaching of the freshman-level course, and later his upperclass course in Plant Physiology.

The River Labs component of the Introductory Biology course that initiated Baker’s involvement in water quality research was discontinued in 1974. On the other hand, his expanding research program provided advanced educational opportunities for numerous students in several important ways. Between 1970 and 1977, the National Science Foundation (NSF) funded a number of student-initiated and directed summer research projects through its Student Originated Studies Program. Students from Heidelberg and other colleges received grants ranging up to $16,930 for water quality projects on the Sandusky River in which lead student researchers recruited other students to work on their projects, controlled budgets and reported their findings to the NSF. David also received NSF funding in 1974-75 for the creation of a junior-level Aquatic Ecosystems course and a senior-level Research course, providing additional opportunities for Heidelberg students seeking to advance their study of water quality issues.
At the same time, the Lab’s increasing need for physical space had become a serious constraint on its ability to capitalize on developing research opportunities. Still operating out of the initial 600 sq ft of space set aside in 1968 in the basement of Laird Hall in support of the Introductory Biology River Labs sequence, Baker turned his attention to space in the basement of Bareis Hall left undeveloped since the building’s construction in 1964. The Departments of Chemistry and Physics, however, also had plans for this area. With Baker’s progressive withdrawal from teaching in the basic Biology curriculum and the Lab’s interest in expanding into space desired by other Departments, a certain amount of friction between various faculty members in the Sciences was almost inevitable. On the other hand, the significant funds brought to the College through Baker’s successful grantsmanship and the prestige that his high-profile research was bringing to the institution was a plus recognized by all.

In 1976, Heidelberg’s Administration commissioned an inter-departmental committee (chaired by Biology’s George Barlow) to examine space and facilities needs among the Sciences, which resulted in a Memorandum of Understanding agreed to by all parties. On the basis of this work, the River Studies Lab was reassigned to several rooms in the basement of Bareis Hall, where the Lab would remain (with several additional expansions to about 5,000 sq ft) until moving into the top floor of the newly built Gillmor Science Hall in 2005.

The Sandusky River Basin Symposium

In the nine years from 1969-1975, the River Studies Laboratory received over $375,000 in grants and had grown into a $100,000 per year research facility employing 13 part-time student research assistants under the direction of Jack Kramer (still the Lab’s only full-time employee). By that time, the Lab’s extensive data on the Sandusky River led to it becoming one of the best studied riverine systems in the world. With growing interest in the ecology of lotic (flowing) waters, the time seemed ripe to convene a conference focusing on the Sandusky and its watershed.

Around this time, David got to know Bayliss (Rock) Prater, a graduate student of William Jackson at Bowling Green State University’s Environmental Studies Center. Prater was completing his Ph.D. work conducting studies on benthic macroinvertebrates in the Sandusky River after having spent several years working for the USEPA on a Lake Michigan water quality project based out of the agency’s Central Regional Lab in Chicago. David and Rock began exploring the idea of bringing together researchers working on the ecology of the Sandusky River and similar riverine projects to share insights on what they had learned and their thoughts on directions for future research.

Jackson obtained a $5,000 grant to fund the conference and the Sandusky River Basin Symposium was held May 2-3, 1975 at Heidelberg College. The meeting (jointly sponsored by Heidelberg and BGSU and co-chaired by Baker and Prater) was divided into four sessions: Geology, Land Use and General Water Quality; Biological Water Quality Indices; Sandusky Bay and Upground Reservoirs; and Governmental Planning. Over 150 attendees saw 33 papers and discussions delivered by 39 presenters and 6 panelists. Michigan State University’s Kenneth W. Cummings’ Keynote...
address focused on the necessity of evaluating all running water systems within the context of “overall watershed influences,” and included the first public presentation of his influential River Continuum concept. The resulting 475-page proceedings was published by the International Joint Commission.

In 1976, Baker invited Prater to join the Lab as its Associate Director overseeing the lab’s expansion of biological studies in the Sandusky River Basin and elsewhere. (During his first years at Heidelberg, Bayliss also served as a sabbatical replacement for Robert Murray in the Biology Department.) In 1977, Prater published a description of a 96-hour sediment bioassay procedure for documenting the effect of pollutants in lake and stream bottom sediments on macroinvertebrates. The method, developed during his work with the USEPA and tested while at Heidelberg was to become a standard procedure adopted by researchers investigating the impact of polluted sediment on aquatic organisms.

Also in 1976, the Army Corp of Engineers, instituting Phase II of its Lake Erie Wastewater Management Study, provided the Lab with a $134,424 grant to expand its work on the Sandusky River and to initiate a water quality study of Honey Creek. A tributary to the Sandusky, Honey Creek’s agriculture-dominated watershed was to be part of a Corp demonstration project exploring the effect of recently developed conservation tillage methods in reducing phosphorus loading into tributaries feeding Lake Erie.

Arguably of greatest importance to the long-term success of the lab, however, 1976 also saw the hiring of Heidelberg alumna D. Ellen Ewing as the Lab’s second full-time laboratory technician (after Jack Kramer’s employment seven years earlier). In 1978, Barbara Merryfield, also a Heidelberg graduate, joined Ellen in the Lab’s analytical chemistry section. Like Ellen, Barb’s willingness to take on new responsibilities and to shoulder enormous workloads when necessary proved central to lab’s evolution into one the most trusted water quality research facilities in the nation. Much as Jack’s manifold talents in physical chemistry, electronics and computers enabled the lab to adopt (and often invent) automated technologies years ahead of other laboratories, Ellen and Barb’s competence and sterling commitment to the Lab’s mission over the years became one of the pillars underlying the laboratory’s developing international reputation for excellence.

When outside researchers toured the Lab, one of the responses most often voiced was a sense of wonderment at the long-term stability of its core team of research professionals. Over the years, Baker employed a number of skilled research assistants to work with Ellen and Barb on various projects, some of whom played important roles within the Lab for several years before moving on to other opportunities. But it is clear that the core team of Jack, Ellen and Barb’s long-term commitment to Dave Baker and his vision of what the Water Lab could accomplish explains much of why and how it has in fact achieved so much. Ellen assumed the role of Laboratory Manager on Jack’s retirement in 2012 and equaled his remarkable record of 43 years of employment in 2019.

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1 In International Joint Commission-sponsored round-robin tests in which water samples and blind controls were distributed to various facilities, analyses performed by Heidelberg’s Lab were always spot on.
**The Water Quality Laboratory and the Roger R. Simons**

With Dave Baker’s expanding interests in all manner of environmental water quality issues, the Rivers Studies Laboratory name adopted in 1974 was becoming less descriptive of the Lab’s diverse research program. In 1977, it became the Heidelberg Water Quality Laboratory (WQL), the title it would carry until 2002 when an act of Congress renamed it the National Center for Water Quality Research (NCWQR).

In 1975, as part of an International Joint Commission agreement to monitor the effectiveness of pollution abatement programs in the Great Lakes, the USEPA initiated a multi-year water quality study that was to examine each of the Great Lakes in turn. Lake Erie was scheduled for 1978-9. In his earlier work for the USEPA on Lake Michigan, Rock Prater had spent a significant amount of time aboard the Roger R. Simons, a former U.S. Coast Guard buoy tender that had been converted into the third largest research vessel operating on the Great Lakes. Through this connection, Prater received a request from the Chicago office to submit a grant proposal for a 2-year study of water quality in the nearshore waters of Lake Erie.

In 1978, the WQL received a $633,076 grant in support of the two-year Lake Erie Intensive Study (commonly referred to as the Nearshore project) during which the Simons (Figure 2) was to be leased to Heidelberg College for one dollar per year. The R/V Simons (named after an EPA biologist who lost his life in 1970 while collecting water samples on the Mississippi River) was a 122 ft, 340-ton shallow draft vessel that slept 20. The research team of water chemists and biologists under Prater’s direction had to first retrofit the Simons with a (reasonably) seaworthy analytical lab for on-the-spot chemical, phycological (algal), microbiological and macrobiological sample analyses.

![The Roger R. Simons in calm waters, flying Heidelberg’s flag on its mast. The Simons underway during less benign conditions. (NCWQR illustrations archive)](image)

The WQL’s responsibilities in the study were to collect and analyze water and bottom sediment samples from 89 stations within a 3-mile-wide zone stretching from Sandusky Bay to Ashtabula. A research team from the Ohio State University undertook a similar study for nearshore areas of the Lake’s western basin while a third team from the Buffalo State College,
SUNY worked the eastern basin. Canadian researchers surveyed nearshore areas on their side of Lake Erie while USEPA vessels performed mid-lake analyses.

The project’s grueling schedule called for four 15-day cruises: shortly after ice breakup, early summer, late summer and late fall. Jack Kramer, Ellen Ewing and Francine Turose (hired in 1978) worked in the onboard wet lab while Barb Merryfield conducted additional analyses at Heidelberg. Prater hired a number of biologists he had previously worked with during his time with the USEPA and BGSU including Paul Crerar, Paul Flathman, Phil Kline, Robert Hoke and Peter Pryfogle who was to be the chief onboard scientist. Also hired in separate searches at this time were Chemical Limnologist R. Peter Richards and benthic invertebrate biologist Kenneth A. Krieger, each of whom would eventually serve terms as Director of the Lab (Richards 1999-2002, Krieger 2010-15). The ship’s crew had been hired by a company contracting with the USEPA office in Chicago.

All told, by the end of 1978 the WQL’s staff had expanded to 18 full-time professional, technical and administrative employees. As often transpires, following the first year of the Lake Erie Intensive Study there were significant concerns whether the EPA was going to support the second year of work fully, partially or not at all. In the end, however, the project did run as planned with Heidelberg gaining full control of the ship—not only providing the scientific staff but also taking responsibility for outfitting the ship and its crew. Although the WQL completed its obligations on time and within budget, submitting to EPA all of the high-quality data and analyses the agency had expected (and more) from the study, the two years of project also represent one of the most difficult periods in the Lab’s history.

From almost the beginning of the two-year study, tensions between “Baker’s chemists” and “Prater’s biologists” were apparent. As early as July 1978, Heidelberg’s President at the time, Leslie H. Fishel, was exchanging memoranda with Academic Dean Arthur R. Porter about divisiveness within the WQL staff. Prater and Kramer did not get along and Rock was already speaking about leaving after the first year of the study. In a 2018 interview, Rock recalled that part of the friction stemmed from a clash of two different cultures; the biologists were mariners the chemists were not, and the shipboard environment is a “whole different world.” Forty years later, however, Ellen, Barb and Jack still retained bitter memories of numerous negative interpersonal interactions with Rock and certain of the biologists he had hired, which only worsened during the second year of the project.

Matters came to a head early in 1979, necessitating the intervention of Dean Porter who, in an attempt to understand the primary sources of friction within the WQL, both on and off the Simons, interviewed each member of the staff. His analysis identified a set of both structural and inter-personal conflicts that threatened not only the viability of the Nearshore project but the continuing existence at Heidelberg of the team of professionals that Prater and Baker had assembled. Emblematic of the deep divisions separating the chemists and biologists, when on campus the two groups were physically separated on opposite sides of the hallway in the basement of Bareis. While activities of the chemical branch included work on contracts other than the Nearshore project, the biologists’ work focused almost exclusively on that study, and their futures with the lab at its conclusion was far from clear. The on-again, off-again status of the project’s second year exacerbated tensions within the group.
During the second summer’s field season, the situation had deteriorated to the point where Porter deemed it necessary to visit the Simons to address several of the more serious management and inter-personal relationship issues. Whatever David Baker’s strengths had been in not only bringing the Lab into existence but into a prominent position as one of the leading, independent water quality research organizations in the nation, the ability to address such an array of internecine conflicts within his staff was not one his skills. Shortly after the end of the 1979 field season, Prater left Heidelberg to continue the development of an aquatic consulting firm in the neighboring town of Melmore, Aqua Tech Environmental Laboratories that he had purchased several years earlier. Following the conclusion of the Nearshore Study, Pryfogle, Crerar and Hoke joined him there. Flathman and Kline left for other opportunities within the next few years, leaving Ken Krieger and Pete Richards as the only two hires for the Nearshore project to remain as permanent WQL employees.

And the Water Quality Lab continued on. One of the most positive aspects of the Lake Erie Intensive Study from the Lab’s perspective was an improved understanding of the interface between Lake Erie’s nearshore areas and the tributaries feeding into them. A second was to bring WQL staff members into contact with other researchers working on a diversity of Great Lakes projects. Both outcomes were to benefit the WQL by broadening its researchers’ perspective and presenting opportunities for future collaborations. By the end of 1979, Baker was able to report that the Lab had received over $2 million in grants and contracts from federal, state and municipal governments, industries and private organizations in support of its many research activities—$155,000 of which were received in 1979 as the Nearshore project was winding down.

To the frank surprise of many professional water scientists, “Data Dave” had shown that the small team of committed researchers and technicians he had assembled at Heidelberg was more than able to hold its own in the highly technical field of water resources studies dominated by well-staffed governmental and major university research units. A letter to David on the occasion of his (first) retirement in 1999 from Fred Swader, USDA National Program Leader-Water Quality, expressed the point well.

I must admit there was some skepticism among many here in USDA regarding a professor from Heidelberg! After all, that isn’t even an experiment station of the Ohio State University! And generally, we were not disposed toward favorable opinions of either private colleges or their professors. Well you sure changed that! ... No one in water quality now asks Where is Heidelberg University? or Who is David Baker?

More importantly, the Water Quality Lab had convinced researchers across the nation of the value—and feasibility—of conducting intensive, long-term, watershed-based monitoring of aquatic systems. The leading questions now were how to analyze and interpret the masses of data generated by such studies and what might be the implications of those analyses for managing the nation’s water resources? That and the ever present and enticing question, “What’s next?


Chapter 3. 1980-1999

Contaminants in surface waters

The next two decades would see the WQL’s expanding research interests lead to insights on the nation’s water resources with consequences for management extending far beyond the Sandusky River Basin.

One of the new directions of study opening up for the Lab at the close of the 1970’s entailed research into the effects of a new generation of pesticides* on the waters of agriculture-dominated watersheds. The term “new generation of pesticides” merits some discussion. The introductory paragraph from a 1993 paper by Pete Richards and David Baker† is useful here:

In the thinking of the public and even of many environmental scientists, the term pesticide carries connotations that are a legacy of DDT and other organochlorine compounds, most of which are no longer used or are of very restricted use in the United States. These connotations include bioconcentration, fat solubility, limited solubility in water, and resistance to degradation, all of which led to substantial and lasting impacts on nontarget organisms, particularly top predators in the food chain. By contrast, most of the pesticides in use today, at least those used on row crops in the Midwest, are transported in aquatic systems primarily in the dissolved state, have much shorter half-lives, are subject to minimal bioaccumulation, and have smaller impacts on nontarget organisms. This is particularly true of herbicides, which are used in much greater quantity than insecticides and other pesticides.

These comments notwithstanding, herbicides remain (by far‡) the major pesticide concerns as pollutants in the nation’s agriculture-dominated watersheds. But in the early 1980s, systematic water sampling for modern agrichemicals was not being undertaken anywhere in the nation as they were not expected to pose much of a problem. In the post-Silent Spring era, most of the long-lasting pesticides like DDT had been banned in the U.S. and existing governmental monitoring programs were focused on how their breakdown products were diminishing in the nation’s surface waters. No drinking water standards for their replacements had as yet been established so they were not being closely monitored. In fact, suppliers were commonly prohibited from charging customers for testing for the presence of compounds for which standards had not been set.

However, as conservation tillage methods (involving no or reduced-tillage of fields in preparation for seeding) were being increasingly touted as effective means for reducing phosphorus inputs into Lake Erie, environmental groups began raising red flags over the potential for contamination of water bodies by the herbicides being widely used to control weeds in unplowed fields. Although many of these compounds had been in use since the 1960s as

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*Though the term, pesticide, is commonly considered equivalent to insecticide, in the scientific literature it is a general term referring to insecticides, herbicides, fungicides, rodenticides, nematocides and other pest killers.
†Contrary to common perception, herbicides account for over three-quarters of synthetic pesticides in use by commercial Agriculture.
supplements to plowing in weed control, their use was greatly expanded with the adoption of conservation tillage methods. Agricultural researchers at the time were aware of these herbicides’ off-field movement, but their subsequent fate in stream systems had received very little study.

In 1981, the Lab began the first of its long-term studies assessing the presence of pesticides in area rivers and streams, using much the same methods as it had developed for its nutrient studies. Funding from CIBA-GEIGY (maker of atrazine) enabled the lab to adopt newly available gas chromatography methods for rapid analyses of up to 21 chemicals in a single water sample, a great improvement over previous techniques allowing for just 2 or 3. In doing so, Ellen Ewing and crew soon found readily detectable amounts of herbicides in rivers, especially after storm events following spring field applications of the compounds. Even more surprising was the 1983 discovery of significant summertime concentrations of herbicides in tap water being delivered (as drinking water) to consumers.

A grant from the Joyce Foundation sponsoring a study of finished water coming out of water treatment plants in Bowling Green, Tiffin and Fremont Ohio found that the concentrations of six herbicides—the acetanilides alachlor (Lasso™) and metolachlor (Dual™); the triazines atrazine (AAtrex™), cyanazine (Bladex™) and simazine (Princep™); and the urea herbicide, linuron (Lorax™)—in the tap water of Bowling Green and Tiffin closely matched those observed in source river waters (the Maumee and Sandusky), and that concentrations of atrazine and alachlor ran higher than those reported for municipal water supplies in Iowa, Nebraska and New Orleans. This was unexpected since older pesticides typically attached themselves to sediment particles that are removed by filtration processes in water treatment facilities. But unlike the older generation of pesticides, members of this new class of agrichemicals were water soluble and largely sailed right through water treatment plants.

Unlike Tiffin and Bowling Green, the city of Fremont had a major food processing facility and its water treatment plant took the extra step of running its water from the Sandusky through activated carbon (primarily to reduce taste and odor issues associated with algae) which, incidentally, greatly reduced the concentration of soluble herbicides. The Lab’s report on this study was widely distributed and was cited in the Congressional Record as a reason to request the USEPA to develop datasets that might be useful in establishing drinking water standards for these agrichemicals. The Lab’s work on alachlor, the first of the new generation herbicides to be evaluated, constituted 40% of all data submitted to the EPA in its national call for data on the compound in public drinking water supplies.

In a 1985 paper, Baker et al. wrote “The basic problem of quantifying cropland impacts in regional water quality is one of accurately characterizing highly variable systems.” With appropriate equipment and trained staff, it’s a fairly straightforward task to measure the concentrations of nutrients, pesticides, sediments, pharmaceuticals and other pollutants at a particular sampling station on a given day and hour. However, if the goal is to characterize the overall chemical profile* of a river or stream, it will be necessary to devise a sampling scheme

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*The chemical nature of a water body is central to what is sometimes referred to as its environmental “quality” or “health.” Environmental quality implies suitability (relative to regulatory agency established standards) for a
that takes into consideration variability in pollutant concentrations on scales ranging from hour-to-hour to seasonal, year-to-year and even decade-to-decade fluctuation. Just as for nutrients, the automatic samplers are set to collect three samples per day (4 AM, 12 PM and 8 PM), with sample pick up at weekly intervals (Mondays). For days when runoff events are occurring, all three samples are analyzed, while for non-storm-event days, only the noon sample is analyzed.\(^4\)

The factors influencing pollutant loading observed at a given river location within a set time period are legion: weather conditions, rate of flow, watershed size, geology and land use, demographic factors, point and nonpoint sources of pollution, seasonal and year-to-year shifts in land management practices (reflecting local, national and international economic factors), pollution abatement programs and technical innovations in farming. As Baker has noted, each of these factors affect the chemical components within a stream differently. Consequently, it is literally true that, as Plato paraphrased Heraclitus, “You could not step twice into the same river.” Determining the relative importance of these factors in understanding variability in pollutant concentrations within riverine systems has been a long-term objective of the Lab’s Lake Erie Tributary Loading Program.

A first step in doing so was finding effective ways to summarize the massive amount of data accumulated by the Lab for a given watershed in such a way that patterns in pollutant concentrations within its waters might be revealed. Plotting the mean monthly concentration of a pollutant for a given river or stream over the course of a year provides useful insights, as is illustrated in Figure 1, which summarizes data for the three most heavily used herbicides in the Lake Erie Basin over the six years from 1983-88 in three watersheds.

Figure 1. Monthly Time-weighted Mean Concentrations (TWMC) for three herbicides, averaged over six years (1983-1988) for three Northwest Ohio watersheds. (Richards, R.P. and D.B. Baker, 1993)

Here, the average concentration of a pollutant for a given month is calculated as a Time-weighted Mean Concentration (TWMC) measured in micrograms per liter. “Time-weighting” is necessary because the samples are analyzed more frequently during runoff events when concentrations are much higher than during non-storm-events which have lower concentrations. Consequently, to determine an average concentration over the entire period (when both high and low concentrations may have occurred) each sample is “weighted” by the duration of time it is used to characterize the stream. These time-windows are calculated as one half of the length of designated purpose such as swimming, fishing, irrigation, etc. The environmental health of a water body, sometimes referred to as its “biological integrity,” focuses more on its ability to sustain a diverse biota.\(^1\)

Determining the most efficient sampling regimen to adequately chronical pollutant loading within a river or stream throughout the year has been one of Pete Richards’ areas of interest.
time between the previous sample and the following sample. During high flows when three samples per day are analyzed for several days, each sample represents 0.333 days while during low flows, each sample represents 1.000 days.

Imagine, for example, a May with 5 stormy, high-flow days (with multiple samples collected each day) and 26 clear, low-flow days (represented by only one sample per day). If May’s overall average concentration for a given pollutant was determined as the simple average of all samples taken, a given high-flow day would have a greater effect on the monthly average than a low-flow day because more samples would have been taken on the high-flow day. By weighting the concentration observed in a given sample by its time-window and then averaging all such time-weighted concentrations for the month, this bias is eliminated. So then, for each of the watersheds in Figure 1, similar seasonal variation is seen for the three herbicides with peak concentrations in late spring to mid-summer and higher concentrations of atrazine and metolachlor than alachlor, reflecting the compounds’ use during 1983-1988.

From its earliest nutrient studies in the Sandusky, it was clear that storm events had a significant effect on pollutant concentrations within receiving waters. A graph depicting discharge (flow) rates over time is called a hydrograph, while a plot depicting changes in the concentration of a compound being transported in the water over time is a chemograph. In Figure 2, the hydrograph in the upper left corner presents the flow pattern (measured in cubic ft/second)

![Figure 2. Hydrograph (top left) for ten days illustrating a storm event in Honey Creek in 1986 replotted against the chemographs for seven pollutants in the Creek at that time. (Richards, R.P. and D.B. Baker, 1993)](image-url)
in Honey Creek\(^*\) over a 10-day period following a storm event on May 15, 1986.\(^5\) This hydrograph is also plotted in each of the seven depicted chemographs.\(^†\) Taken together, Figures 1 and 2 illustrate a pattern that was typical of the 1980s and 1990s. Although peak pesticide concentrations for atrazine, alachlor and metolachlor were clearly associated with storm events, the pesticides’ chemographs varied with their mobility and persistence within water and their patterns of use within the watersheds. Other studies comparing rivers with smaller tributaries demonstrated that while smaller tributaries tended to experience higher peak herbicide concentrations than did larger ones, intermediate herbicide concentrations persisted longer in larger tributaries.

Figure 2 shows that although the herbicide chemographs were similar in shape, they differed from those of the other pollutants. While peak pesticide concentrations closely coincided with peak flow, suspended solid concentrations usually peaked prior to peak discharge and nitrates well after it. These differences stemmed from the primary pathways through which the various pollutants moved from field to stream. The largest pulse of suspended solids appears to come with the erosion of loosely fixed soils (especially from stream banks) early in a storm period and from the resuspension of bottom sediments. And while water soluble pesticides primarily enter streams during storms when surface waters carry them off treated fields, a significant percentage of nitrates reach the stream through underground tile systems resulting in increased concentrations during the falling limb of the hydrograph.\(^‡\)

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\(^*\)The Lab’s water sampling stations were situated near USGS Stream Gauging Stations, from which the data for calculating flow rates were obtained.

\(^†\)The concentrations for atrazine, alachlor and metolachlor are given in micrograms/liter while concentrations in the other four chemographs are given in milligrams/liter.

\(^‡\)Phosphorus, as discussed in Chapter 1, turned out to be more complex than originally anticipated, with its particulate and dissolved reactive components behaving differently during runoff events and in-stream.
Having illustrated the complex relationships between storm events and herbicide concentrations within rivers and streams, it was not surprising to find significant year-to-year variability in herbicide concentrations with a given tributary, as is shown in Figure 3 for a nine-year sequence for Honey Creek. The strikingly similar chemographs closely tracked spring-summer precipitation patterns in those years. Both monthly (jagged line) and annual (shaded bar) time-weighted mean herbicide concentrations were lowest in drought years and highest during years with heavy rains. The horizontal line at 2.0 micrograms/liter (= 2 parts per billion, ppb) for alachlor represents the Maximum Contaminant Level (MCL) for drinking water set by the US EPA in 1992. Also established at that time was the depicted MCL for atrazine at 3.0 µg/L (3 ppb). MCLs are EPA-established regulatory standards by which water treatment plants must abide. They are based on Lifetime Health Advisories (LHAs), recommendations developed by EPA’s Office of Drinking Water for pollutant concentrations that are deemed to pose no significant adverse health effects when consumed over the course of a lifetime. At this writing, the EPA has not established an MCL for metolachlor; it has a LHA of 525 µg/L.

The extent to which atrazine and alachlor exceeded their MCLs and metolachlor its LHA within Honey Creek over the years from 1983-7 can be visualized with the “concentration exceedency curves” presented in Figure 4. The three curves depict the percentage of time a given concentration of herbicide was exceeded. For example, during this five-year period atrazine concentrations exceeding its MCL of 3 µg/L were recorded about 18% of the time while a concentration of 12 µg/L was exceeded in about 3% of the time. Remembering that the Lab collected and analyzed samples more frequently during storm events when herbicide concentrations were known to be at their highest, should these curves be interpreted as indicating a biologically important problem with atrazine pollution in Honey Creek?

*MCLs have not been established for water obtained from privately owned wells.
**Impartial evidence-based science vs. biased misuse of science: a case study of two perspectives**

The fact that the chemographs for Honey Creek showed peak atrazine and alachlor concentrations exceeding their MCLs in at least one month during most years leads to questions about implications for that stream’s plants and animals. Of greater concern, given similarly shaped chemographs for the Sandusky and Maumee Rivers presented in Figure 5, questions might also be raised over potential risks to human health since each river serves as a source of drinking water for several urban communities.

![Monthly and Annual Time Weighted Means](image)

**Figure 5. Annual variability in the concentrations of atrazine and alachlor in the Sandusky and Maumee Rivers, 1983-1991. (NCWQR illustrations archive)**

Atrazine provides a useful illustration of the difficulties encountered in determining (and then communicating to the public) the nature of such risks. In its analysis of 649 samples for the Sandusky and 599 samples for the Maumee Rivers from 1983-91, the Lab found mean annual concentrations of 1.30 and 1.33 µg/L for the Sandusky and Maumee—less than half the 3.0 µg/L MCL set for atrazine. On the other hand, concentrations of the herbicide during the nine years of the study exceeded its MCL in 14% of samples from the Sandusky and 17% from the Maumee, with maximum observed concentrations of 24.6 µg/L and 21.5 µg/L.\(^*\)

The EPA’s LHA recommendations and MCL standards are based on mean annual exposure rates but the seasonal spikes in herbicide concentrations cannot be ignored. What would be the most

\(^*\)In ecological risk assessment of herbicides, the upper 90\(^{th}\) percentile concentration (the value above which lie only 10% of all observed concentrations) is often of more interest than mean or maximum concentrations. The 90\(^{th}\) percentile concentrations during this period for the Sandusky and Maumee Rivers were 3.77 and 3.81 µg/L.
scientifically conscientious and ethically responsible manner for the Lab to convey to the general public its understanding of health risks associated with its atrazine findings in these rivers? What recommendations, if any, ought the Lab provide to governmental regulatory agencies concerning the use of atrazine? Other research teams studying triazines in Midwest drinking water supplies at this time sometimes answered such questions very differently than did the Water Quality Lab’s researchers.

In October, 1994, the environmental advocacy organization, The Environmental Working Group (EWG), released a report entitled Tap Water Blues via a series of news conferences across the country. Stating that herbicides in drinking water pose the greatest pesticide-related public health issue facing the nation, the authors called for a complete phase out of all uses of three triazine herbicides (atrazine, cyanazine and simazine) by September, 1996 and immediate action by the EPA to set enforceable MCLs for all triazines at levels that would present no more than a one-in-a-million cancer risk. The EWG’s analyses and interpretations were based on a data set of some 20,000 samples of finished tap water obtained from various publicly available sources throughout the Midwest’s area of heavy herbicide usage. From this they characterized herbicide concentrations for the three triazines (and two acetanilides, alachlor and metolachlor) for individual cities and towns throughout the study area, focusing on surface water supplies having the highest concentrations.

Next, using cancer potency factors (that relate herbicide dosage to the risk of contracting cancer) and the reported concentrations of each herbicide, the authors calculated cancer risks associated with each herbicide individually and then summed the risks for the five herbicides to provide an aggregate cancer risk for each community. The resulting aggregate cancer risks were then organized in a wide variety of ways to describe excess cancer risks from herbicides throughout the region. Among the chief findings in Tap Water Blues and Press Advisories accompanying its release were:

1. Federal drinking water standards are among the weakest of all national environmental regulations.
2. 14.1 million people routinely drink water contaminated with five major agricultural herbicides (atrazine, cyanazine, simazine, alachlor and metolachlor).
3. More than 3.5 million people in 120 cities and towns face cancer risks more than 10 times the federal cancer risk benchmark, based on average annual exposures to these herbicides.
4. Across the Corn Belt, at least 241,000 individuals are supplied by surface water sources where average annual herbicide levels exceed federal standards.
5. In the Corn Belt, an estimated 65,000 infants drink these herbicides from birth via infant formula reconstituted with contaminated tap water.

Understandably, the media blitz accompanying the release of this report alarmed many Midwestern residents and they sought explanations and assurance. However, state and local officials responsible for the safety of the public’s drinking water were caught off guard and, generally lacking the specialized training to quickly and effectively analyze and respond to the concerns generated by Tap Water Blues, they were often made to look incompetent or worse. In Tiffin, Dave Baker’s phone was getting a lot of use.
In November 1994, Baker, et al. released a critical analysis of *Tap Water Blues*. The following quote from the first page of the review makes clear their view of the science in EWG’s publication.

While this report represents the most comprehensive study to date of the cancer risks associated with herbicide contamination of midwestern tap water, we conclude that the authors of *Tap Water Blues* have misrepresented the significance of their findings in their press releases to the public through radio, television and newsprint. Furthermore, we see clear indications that the authors deliberately used inappropriate averaging procedures resulting in inflated risk estimates. They fabricated a federal standard against which to compare the risks that they had calculated and presented their results in a way that could easily lead to exaggerated public perceptions of actual cancer risks. They provided virtually no context for the numbers they provide, which are presented so as to generate the greatest public alarm.

An analysis of the review’s attack on the science in *Tap Water Blues* and EWG’s public relations methods for advancing its agenda would require a detailed discussion of EPA’s procedures for determining the risk to human health of a given pesticide, the use of its risk analysis in establishing an LHA and MCL for the pesticide and Baker’s reasons for excoriating the EWG for inappropriate use of EPA standards in calling for the banning of all triazine herbicides. The below five criticisms provide a sense of the Water Quality Lab’s perspective.

1. In analyzing average herbicide drinking water concentrations for a given community, the authors did not use time-weighting (in recognition of much heavier sampling efforts during high flow/high herbicide concentration periods). This resulted in their reporting much higher average concentrations than the data warranted.

2. In calculating “statewide average” herbicide concentrations the authors did not use population-weighting. Thus, in Ohio, the town of Attica with a population of 1,200 and a relatively high aggregate (for all herbicides combined) cancer risk of $45.8 \times 10^{-6}$ contributed equally to the state average as Akron’s population of 280,000 with a risk of $9.7 \times 10^{-6}$.

3. In addition, the authors consistently used the term “statewide” averages even though their study was limited to the 21% of the region’s population experiencing the highest herbicide exposures.

4. While the authors’ calculations of aggregate cancer risks from the five herbicides considered in the study were done appropriately, they then referred to the resulting aggregate risk for a given city as a multiple of EPA’s minimal allowable risk standard of $1 \times 10^{-6}$ (i.e., no more than one new case of cancer per one million people per year). There is no federal standard for aggregate risks; the standard applies to individual herbicides.

5. Although the authors state that cancer risks posed by the three triazines (atrazine, cyanazine and simazine) merit their being banned, they do not report on the reduction in cancers that such a ban would achieve. Their own data for the Midwest shows that the three herbicides together would be expected to cause 2.4 cancers per year among the area’s 11 million residents, and likely much fewer.

Baker’s problems with the science in *Tap Water Blues* aside, he took special umbrage at the EWG’s view that the Water Quality Lab’s analyses were suspect because of its association with pesticide manufacturers, as in this quote from their report (p. 249):

Recent work published collaboratively by researchers at Heidelberg College and Monsanto corporation (the manufacturer of atrazine and alachlor) concluded that the entire population of Ohio,
including the population served by Lake Erie and the Ohio River, is exposed to herbicides in drinking water (Richards, et al. 1994). Not surprisingly, the Heidelberg/Ciba analysis then concluded that these pesticides did not pose health risks because they were below EPA standards ...

In a rare instance of publicly expressed pique, Dave made his feelings on the matter clear:

If the authors of Tap Water Blues, or indeed any other researchers believe our analyses and interpretations have been biased by a purported “sweethart” relationship with any of the numerous private and public organizations that have supported our research, they are encouraged to illustrate their accusations with reference to our publications. No more serious assault on a scientist’s integrity can be mounted than to impugn his or her impartiality and honesty. To do so without credible evidence amounts to professional slander. We consider our objectivity to be our major asset, for it allows us to work with all parties who seek to bring objective science to bear on environmental issues.

On the other hand, the record is clear in Tap Water Blues. The authors’ analytical methods, interpretations, and media releases all point to a political agenda that they have attempted to advance through creating public perceptions of health risks far in excess of conclusions warranted by their investigations. We do not make this statement lightly. In fact, the bulk of this rather lengthy critique has consisted of our efforts to document a consistent lack of objectivity running throughout much of Tap Water Blues.

In addition to discounting the criticisms of Baker et al. in its 1995 online response to the review, the EWG observed that since the publication of Tap Water Blues, the EPA had denied a request by atrazine’s manufacturer to increase the herbicide’s MCL by a factor of seven, initiated a Special Review of the three triazines analyzed in its report, and worked with DuPont to phase out its production of cyanazine. In the EWG’s view, “These decisions, which were taken by the agency in response to their own internal scientific evaluations, substantially validated virtually all of the findings in Tap Water Blues.” EWG followed up Tap Water Blues with Weed Killers by the Glass in 1995 in which the authors reported on the results from the first half of a 10-week study of atrazine and cyanazine concentrations in finished tap water from 29 cities, mostly from the cornbelt. Results of the second half of the sampling period were published in a series of “Updates,” with both documents again calling for a ban on all triazine herbicides by September 1996. Of his seven main criticisms of the science in Weed Killers by the Glass, the Updates and EWG’s media releases, the following two examples of Baker’s responses to EWG statements offer a sense of his exasperation with the organization’s research procedures and its methods of communicating their results.

1. “Herbicide levels in drinking water soar above the federal standards in much of the Midwest during the summer according to a new study.” —a Time Magazine quote (August 28, 1995) referring to Weed Killers by the Glass.

Baker’s response: “Nowhere in Weed Killers by the Glass does the Environmental Working Group mention the fact that compliance with federal standards for protection against chronic effects (i.e., MCLs) is based on comparison of annual average pesticide concentrations with

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*This request was based on new research accepted by the EPA indicating that the dosage for which no observable adverse effects are seen in animal studies was actually 7.3 times higher than the value used by the EPA when initially setting atrazine’s MCL at 3 µg/L.

†Cyanazine was banned in the U.S. in 2003 prior to which it was the nation’s fourth most heavily used herbicide.
the federal standard. … To assess acute health risks associated with peak concentrations of atrazine during the spring runoff period, the Environmental Working Group should be comparing its peak concentrations with 1-day and 10-day HAs [Health Advisories] for children (100 ppb) and their shorter-term average concentrations with the 7-year health advisories for children. The Environmental Working Group does not even mention the existence of 1-day, 7-day and 7-year health advisories for children.”

2. “Claims of safety associated with these routine and often persistent high exposures find a slender scientific basis in the peer reviewed literature. In fact, there are no data to support the claim that exposure to repeated and sustained levels of weed killers above the MCL, sometimes at very high levels, presents the same level of risk as constant exposure at an average dose of these compounds, as occurs in all animal studies submitted to EPA. Animals are simply not tested in a manner that in any way approximates the varying high and low doses received by millions of people in the Midwest.” --*Weed Killers by the Glass*, Community Updates.

Baker’s response: “The Environmental Working Group is generally correct in stating that animals are not tested in a manner that in any way approximates the varying high and low doses received by millions of people in the Midwest. However, it certainly cannot be stated that animals are not exposed to high doses of pesticides. When continuously exposed to doses 5,000-fold higher than the atrazine MCL for a large portion of their lifetime, even the most sensitive test animals show no adverse health effects. The atrazine MCL is set at a dose 5,000-fold lower than the NOAEL [no observable adverse effect level] for these test animals. In contrast, the peak, short-term exposure to atrazine in human drinking water (Danville, IL) was only 6-fold higher than the MCL. For other cities tested, short-term peak atrazine concentrations were, at most, 3.3-fold higher than the MCL. If continuous exposures at concentrations 5,000-fold higher than the MCL cause no adverse health effects in the most sensitive animals, should we be concerned about a peak daily exposure 6-fold higher than the MCL, or three-month average exposures 2-fold higher than the MCL?”

This rather lengthy overview of some of the principle elements in the dispute between the Environmental Working Group and Heidelberg’s Water Quality Laboratory over the safety of observed levels of atrazine in the nation’s drinking water supplies can serve as a case study of the challenges facing scientists attempting to address complex issues with significant economic and societal consequences. It’s difficult enough when investigators challenge the validity of each other’s scientific methods but even more unsettling when researchers’ professional integrity is disputed. Such was the situation Dave Baker encountered in 1997 with the release by Dan Fagin, Marianne Lavelle and the Center for Public Integrity of *Toxic Deception: How the Chemical Industry Manipulates Science, Bends the Law, and Endangers Your Health.*

Environmental author Dan Fagin was a 1994 Pulitzer Prize finalist and Marianne Lavelle a Polk Journalism Award recipient and senior editor at U.S. News and World Report. The Center for Public Integrity, founded in 1989, identifies itself as a nonpartisan, non-profit organization whose mission is “to serve democracy by revealing abuses of power, corruption and betrayal of public trust by powerful public and private institutions, using the tools of investigative journalism.” *Toxic Deception* quickly received a number of largely favorable reviews as typified by this December 1996 pre-release review in Publisher’s Weekly:

The authors present a very frightening and, unfortunately, a mostly credible account of the ways in which the chemical industry and its lobbying arm have been able to shape and subvert federal
legislation ostensibly designed to protect consumers as well as the environment. Delay, scientific abuses, media manipulation, and political strong-arm techniques are all documented.

In a little over two pages (57-59) of the section of the book dealing with how the chemical industry allegedly taints academic research, Dave Baker and the WQL’s work was presented as a prime example of how industry funding can bias researchers’ presentation of their data:

…A closer look at the work of one of the most prolific researchers on herbicide pollution—David B. Baker of tiny Heidelberg College in Tiffin, Ohio—shows how industry funding can help to shape the scientific debate.

…By the early 1990s, Baker’s tone had changed significantly. The herbicide contamination problem had become a major issue, and Baker was getting almost a third of his research money from Monsanto, Ciba-Geigy, DuPont and other industry sources.

…Six months later, Baker was a key part of the industry’s damage-control strategy after the Environmental Working Group’s release of *Tap Water Blues*.

…There is no factual contradiction between Baker’s early and late work on herbicide pollution. What changed is his tone. His early government-financed research played up the extent of contamination; the later industry-financed studies played down the health threat posed by that contamination. … Adds Richard Wiles of the Environmental Working Group, a frequent Baker antagonist: “He was one of the guys way back when who identified this as a problem. And the tone of his data, the interpretation of his data, has changed as his funding source has changed.”

As Dave noted in his above comment addressing similar accusations made against him in *Tap Water Blues*, “No more serious assault on a scientist’s integrity can be mounted than to impugn his or her impartiality and honesty. To do so without credible evidence amounts to professional slander.” Much of the evidence used in *Toxic Deception* appears to have come from an hour-long phone interview Fagin conducted with Baker in 1996 after which Dave had sent him a few reprints of the Lab’s pesticides reports and a copy of the Lab’s 1994 Annual Report containing an overview of the WQL’s various programs, its final budget for 1993-1994 and projected budget for 1994-1995.

In a January 18, 1998 letter to Fagin, Lavelle and the Center for Public Integrity, and again in a February review of this segment of *Toxic Deception*, Baker addressed each of the authors’ contentions. Among other criticisms, Baker observed that:

The thesis that our tone changed as we began to receive money from pesticide manufactures does not hold since we have received such support throughout the entire period of our studies. … We received more support from pesticide manufacturers in 1985 and 1986 than we did in 1995.

Our average annual percent income from pesticide manufacturers during the 1990s was 13.4% of our total income [as opposed to the “almost third” stated in *Toxic Deception*].

You do not contest any of my criticisms of EWG work; you simply ignore them. In fact, you do not provide a single example of any of my writings that reflect an industry biased tone or spin, nor any example where our conclusions were not warranted by the available data.
What is an impartial observer to make of all of this? Is this a case of two groups of well-intentioned and ethically-motivated scientists whose analyses of their data led them to opposite conclusions on a topic with far-reaching societal implications? Or did one group, the other or both appear to have intentionally structured their analyses so as to reach a predetermined set of results? Were research results communicated—“packaged”—to support a particular viewpoint when an alternative presentation would have supported a quite different interpretation?

If advocacy groups like the Environmental Working Group and the Center for Public Integrity have reason to suspect the untoward influence of industry’s deep pockets on public discourse in areas of economic interest to them, rank-and-file scientists also have cause to decry the limited oversight such advocacy groups face in communicating their message. With no disrespect to the internal fact checkers and outside reviewers who examined early drafts of Tap Water Blues, Weed Killers by the Glass and Toxic Deception, the peer review process each WQL paper had to pass through prior to being published in a standard scientific journal is a high bar, a proven safeguard against errors and misrepresentations not required of the EWG and CPI in its publications. And while industrial support for the Lab’s programs might have been cut if its research countered the pesticide manufacturers’ hoped-for results, it is also possible that that Tap Water Blues would have garnered a wide audience for its assertions without the nationally coordinated media blitz orchestrated by the EWG on its release. Both may-have-beens, however, seem unlikely.

In any case, for some time the primary health concern of atrazine (and the other two triazines currently in use, simazine and propazine) has been its activity as a hormone disrupter with reproductive and developmental effects in laboratory animals considered relevant to humans. In July 2018, the EPA released its Draft Human Health Risk Assessment for Atrazine as part of its Registration Review Process. The Risk Assessment and Summary section of the report includes two statements of interest here:

There are no dietary (food), residential handler, non-occupational spray drift, or occupational post-application risk estimates of concern for the registered uses of atrazine.

There are no aggregate (food, drinking water, and residential exposures) risk estimates of concern for the scenarios that were included in the aggregate assessments.

In September 2018, the Environmental Working Group published a strongly worded document on its website attacking the EPA’s actions:

…Yet when the EPA published its latest review of atrazine, new research was discarded, putting the interests of pesticide manufacturers ahead of human health. Overall, the agency:

- Ignored more than 10 human epidemiological studies showing human health harm from atrazine in drinking water;
- Ignored the data showing that atrazine can change brain function and behavior;
- Dismissed the children’s health impacts from atrazine; and
- Discounted the potential cancer risks of atrazine.
In contrast, the Executive Summary of EPA’s Draft Risk Assessment for Atrazine notes:

The SAP (Science Advisory Panel) has supported the Agency’s conclusions regarding atrazine’s neuroendocrine MOA [Mode of Action] and the potential noncancer and cancer health effects associated with atrazine exposures.

A weight of the evidence (WOE) analysis has been completed using the draft “Framework for Incorporating Human Epidemiologic & Incident Data in Health Risk Assessment.” The WOE analysis integrated quantitative and qualitative findings from experimental toxicology studies, epidemiology studies, and PBPK modeling [used in predicting human physiological responses to various doses of a compound].

So the debate over atrazine and related triazines continues.

There was no debate over the hazardous nature of a very different type of contamination issue involving the Water Lab towards the end of its second decade of operation. Around 6 PM on Feb. 17, 1988, workers at Sun Refining & Marketing Company noticed a pressure drop in a pipeline carrying reagent-grade toluene from a Sun oil refinery in Toledo to a refinery in Marcus Hook, Pa. The source of the problem proved to be a rupture in an 18-inch underground pipe near the unincorporated village of Watson, OH in northeastern Seneca Co. The resulting spill of 200,000 gallons (initially estimated at 84,000 gallons) emptied via an intermittent stream into Sugar Creek and thence into the Sandusky River. The spill led to the evacuation of more than 5,000 people from their homes in Seneca and Sandusky counties and fouled the drinking water for over 22,000 people. Governor Richard Celeste declared a state of emergency for Sandusky County, which included the downstream city of Fremont. The parent company Sunoco Inc., which in 1995 admitted to negligence in causing the spill, spent $6.5 million to clean the spill and compensate victims for costs resulting from it, as well as $5 million in attorneys’ fees and $500,000 in other costs.16

Nancy Miller, who had for many years fielded calls to the Lab from the public, said, “The phone was ringing off the hook.” Indeed, the spill made national headlines. In coordination with a set of chemical and biological studies undertaken by the Ohio Department of Natural Resources (ODNR), Ken Krieger initiated a 13-month study on the spill’s impact on the macroinvertebrates of Sugar Creek.17 The spill had caused nearly complete devastation of invertebrate and fish populations in the several miles of Sugar Creek downstream of the spill to its mouth on the Sandusky River. However, Krieger found that the invertebrate groups at three impacted sites “recovered substantially” within 90 days and that by the end of the study they had essentially returned to a “natural condition” in comparison to an unimpacted control site upstream from the spill. As an important side effect, the accident also led the WQL to add the study of volatile organic compounds (VOCs) to its assemblage of analytical capabilities.
Contaminants in rainwater, groundwater and Heidelberg’s return to Sandusky Bay

By 1981, America’s use of herbicides had increased 280% over what it had been in 1966. Much as the Water Quality Lab had been one of the first groups to recognize the importance of storm events in the study of nutrient transport in streams, it had become a leader in the study of water-soluble pesticides in the streams and rivers of agriculture-dominated watersheds. In fact, staying ahead of the curve was to become something of a hallmark for the Lab.

In the early eighties, controversies over the causes and importance of acid rain were in the news and Dave, after having read a report on the presence of atrazine in fog, got to wondering what the literature had to say about herbicides in rainwater. It turned out that only one study had considered the question; a researcher in Maryland had found that atrazine concentrations in precipitation varied considerably throughout the year (reaching a high of 2.19 µg/L), without showing any clear seasonal pattern. The latter observation seemed surprising given the WQL’s data showing strong late spring-early summer pulses of the herbicide in Northwest Ohio streams.

In a 1984 pilot study, the Lab set out a few quart jars with glass funnels around campus to see what might be found in Tiffin’s rainwater. Expecting that concentrations (if present at all) would be so low the samples would need to be concentrated to be detected by the Lab’s equipment, the staff was surprised to find several pesticides in readily detectable amounts. This discovery prompted Baker to seek funding for an expanded study. In the spring and summer of 1985, samples of rainwater were collected in West Lafayette IN, Parsons WV, Potsdam NY and, again, Tiffin OH.

Analyzing the samples for the presence of ten herbicides and three insecticides, the Lab found much lower concentrations of all compounds in the New York and West Virginia samples (where pesticide use was low) than in the Ohio and Indiana samples (where pesticide use was high). Although atrazine was found in concentrations comparable to those reported in the Maryland study, the WQL data revealed strong seasonality, with maximal concentrations in rain following pesticide applications in May declining to unquantifiable levels by the end of July. The results published in the prestigious journal Nature stimulated further work on pesticides in rainfall and played a role in the EPA’s decision to include herbicides in its atmospheric deposition studies.

The Water Quality Lab had by now pioneered intensive studies of pollutants in the streams and rivers, finished tap water and rainfall in agriculture-dominated watersheds. Baker’s team next turned its attention to groundwater. Two government studies released in 1987 highlighted the need for significantly expanded attention to this important resource. An EPA study examining 25 years of USGS data on the extent of nitrate contamination in the nation’s groundwater reported that fewer than five wells had been tested for nitrate in 28% of the country’s rural counties, and a USDA model estimated that some 10.9 million private well systems serving a population of 19.3 million in 1,437 U.S. counties were vulnerable to contamination by nitrates and/or pesticides.

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*Its use of insecticides during this period had increased by only a few percent.
†The American Power Service Corporation helped fund the work—at least partly, it seems, in hopes of diverting some of the public’s growing concern over sulfur-emitting, acid rain-causing power plants.
Unlike pesticides, the EPA’s standards for nitrates in drinking water had been based on extensive studies within human populations (rather than primarily extrapolated from animal studies). The large uncertainty factors included for safety in pesticide standards are therefore not required for nitrates and the EPA had set a Lifetime Health Advisory (LHA) level for adults at 10 mg/L, which was also adopted as the Standard for finished tap water produced by publicly owned water treatment facilities. A point of confusion, however, concerns what’s actually being referred to by the term, “nitrates.”

Consumption of excess nitrogen atoms through food or fluids is associated with a variety of health issues. Infants younger than six months of age are at special risk of developing methemoglobinemia (blue baby disease or cyanosis) and drinking water Health Advisories and Standards have been established with this in mind. The two forms of nitrogen-containing compounds of greatest concern in most water supplies are nitrites (NO2) and nitrates (NO3). Of the two, nitrites are considered more toxic (with a drinking water Standard of 1 mg/L) but are also normally much less abundant in drinking water.

Making things more complicated, the above-mentioned standard for nitrates of 10 mg/L actually refers to the concentration of nitrogen atoms within nitrate molecules. That is, the 10 mg/L standard refers to the concentration of “nitrate-nitrogens” within a water sample. (The same standard expressed for entire nitrate molecules would be 45 mg/L.) Even so, this standard is typically referred to as the nitrate standard. As if this weren’t confusing enough, since nitrites are typically so uncommon in most water, the drinking water standard for all nitrogen found in nitrates and nitrites combined (“nitrate+nitrite-nitrogen”) is the same as for nitrate-nitrogen alone, i.e., 10 mg/L. Unless specifically stated otherwise, in general usage a statement referring to the “concentration of nitrates” in a water sample is understood by water scientists as shorthand for the “concentration of nitrogen atoms found in NO3 and NO2 molecules” within the sample.

It is important to note here that while water produced by publicly-owned water treatment facilities is required to meet federally set water quality standards, no such standards existed for water obtained from privately owned wells. In Ohio, the only required test for a private well is a bacteria test to be performed on its installation. In the mid-1980s, 1,600 community public water systems supplied 8.8 million Ohioans while some 700,000 private systems supplied the needs of 2 million, mostly rural, residents. These private systems are commonly more vulnerable to contamination because they are usually shallower, more often of faulty construction, closer to various sources of pollution and less carefully sited.

Heidelberg’s groundwater testing program grew out of occasional requests from local community members to test their well water for nitrates. Though initial results were alarming in that many of these wells had a high nitrate concentration, it was understood that many of the requests for testing came from well owners suspecting they may have had a problem with nitrate contamination. To obtain a less biased overview of the extent of nitrate contamination in the area’s wells, the Lab began offering low cost nitrate testing to any interested private water supply owner in the county.

*Recall that Health Advisories are recommendations rather than enforceable regulatory Standards.
State funding received in 1986 enabled the Lab to expand its well-testing program to include four Northwestern Ohio counties: Seneca, Sandusky, Wyandot and Crawford. What came to be known as Heidelberg’s Cooperative Well Testing Program (CWTP) was initiated in 1987; by 1988, word-of-mouth had generated enough interest that more than half of Ohio’s counties had participated in the nitrate testing program. In cooperation with Soil and Water Conservation Districts, extension agents and Farm Bureau groups across the state, 80 of Ohio’s 88 counties would eventually participate in the program.

With discovery of pesticides in the surface waters of agriculture-dominated watersheds, concerns about the safety of groundwater extended beyond nitrates to include the agrichemicals in common use to control weeds, fungi and animal pests. There was widespread fear that our slow-moving underground aquifers may have been severely contaminated by overuse of nitrogen fertilizers and pesticides. The Lab took advantage of its statewide collections of water samples to supplement its nitrate analyses with a program examining pesticide presence in a subset of the wells it sampled.

In 1989 the Lab published *Nitrate and Pesticides in Private Wells of Ohio: A State Atlas.* The report included a summary of the WQL’s analyses of nitrates in the 16,166 wells from 76 counties it had examined to that point. In addition to this one-time sampling program, 179 well-owners whose groundwater proved to have relatively high nitrates agreed to participate in a year-round testing regime extending from April 18, 1988 to April 3, 1989 to check for annual variability in nitrates. Each of these participants also had their wells tested for 7 herbicides in common use within the region. In March 1989 a separate group of 351 well-owners from 49 counties (again selected on the basis of high nitrate in their water) participated in a second round of pesticide testing.

The resulting Atlas provided an overview of nitrates and pesticides in Ohio’s waters along with maps presenting the test results for each well within participating counties. The average nitrate concentration for the thousands of samples examined throughout the state proved to be 1.32 mg/L. Some 2.9% of the wells contained nitrate concentrations exceeding or equal to the drinking water standard (set for publicly owned water treatment plants) of 10 mg/L, while 68.2% had concentrations under 0.3 mg/L which is considered below detectability. Interestingly, wells in the counties of heavily farmed Northwest Ohio tended to have the least nitrate contamination while those in the relatively lightly farmed Southern and Central counties tended to show the highest nitrates.

Herbicide concentrations within the subset of wells tested for pesticides were uniformly low. Atrazine, for example, was only found at concentrations over 0.05 µg/L in 4.3% of the 610 wells for which it had been tested, with only 5 of those wells having concentration above 1 µg/L. Similarly, alachlor was only detected in 19 of the 591 wells for which it had been tested, with an average concentration of 1.36 µg/L for those 19.

At least for Ohio, the worst fears of extensive groundwater contamination by overuse of nitrogen-fertilizers and pesticides was not supported by these data. Nitrate contamination did vary within the state and even within counties, but not in any clear association with agriculture.

*To help meet requests from other counties, the Lab initiated a $1.00 per sample fee for Ohio residents.*
or natural sources. Rather, vulnerability to nitrate pollution was most often seen in shallow, badly constructed and poorly sited wells (i.e., near potential sources of pollution such as septic systems and fertilizer preparation stations). In like fashion, the highest herbicide concentrations were found in wells located in close proximity to sites where pesticides were stored and handled. Also, private water systems derived from dug wells or springs were more likely to contain herbicides above 1 µg/L than systems utilizing drilled wells, as they are more susceptible to contamination by surface waters than are drilled wells.

Having worked with the Lab on the Ohio project, the American Farm Bureau Federation supported extending the Cooperative Well Testing Program to other states. By the mid-1990s, the Lab’s groundwater studies had grown to include water samples collected from over 43,000 rural residents from 372 counties in 17 states. In 1996, the Lab published a summary\textsuperscript{23} of its analyses of nitrates and triazine and acetanilide herbicides in 34,759 samples from private wells and springs in the five-state Midwestern region of Ohio, Indiana, Illinois, Kentucky and West Virginia. As for the Ohio study, nitrate and herbicides were found in low concentrations throughout the area except for a few notable hot spots. The median nitrate concentration was just 0.07 mg/L with 3.4% wells exceeding the 10 mg/L standard for finished drinking water. Triazines were detected in 4.9% of 12,362 samples, with the EPA established MCL of 3.0 µg/L exceeded in 0.1% of samples.

The test results for the presence of acetanilides, which were detected in 9.7% of 10,967 samples, were of special interest. Although only 1.1% of all samples exceeded the MCL established for alachlor (2.0 µg/L), this was still much higher than had been observed in previous studies. In a national survey of alachlor in rural wells by Holden, et al.,\textsuperscript{24} only 0.02% of wells contained alachlor in excess of its drinking water standard. After a significant amount of confusion, it finally became clear the five-fold difference in results was largely a function of the technologies used to analyze the samples. In the early 1990s, immunoassay methods for evaluating the presence of chemicals in water samples became available and the WQL adopted the technology for its herbicide studies in private wells. Immunoassay tests had similar detection limits as older chromatographic procedures but were much less costly and allowed the Lab to analyze many more samples per day than previous methods. The lab had begun using the new technology with a large number of samples coming from Indiana.

After much reviewing of procedures, reaffirming results, and consulting with chemists at both Monsanto (the manufacturer of alachlor) and the manufacturer of the alachlor immunoassay kits used by the WQL, it was discovered that alachlor has a breakdown product called ethane sulfonate and that while chromatographic methods analyzing a sample for alachlor do not register ethane sulfonate, the immunoassay technique did. Thus, the new immunoassay tests had given false positives for alachlor when only its breakdown product was present. The situation was complicated by the fact that the procedure was only about 20% as sensitive to ethane sulfonate as it was to alachlor (with which the device was calibrated). So an immunoassay reading, say, of 2 micrograms “alachlor” per liter might actually have contained 10 micrograms per liter of ethane sulfonate and no alachlor at all.\textsuperscript{25}

The Lab’s reports were the first to note the presence of this alachlor breakdown product in groundwater. Interestingly, a subsequent U.S. Geological Survey study found ethane sulfonate to be the most common herbicide-related contaminant of groundwater and future assays for
alachlor were modified to account for its presence. Fortunately, extensive tests have shown the compound to have very low toxicity.

While the WQL had been among the first research groups to pioneer studies of pollutants in rainwater and groundwater, its investigation of the movement of pollutants across the Sandusky River-Sandusky Bay-Lake Erie interfaces was almost without precedent. By the early 1980s, many studies had investigated the transport of pollutants in riverine systems or explored seasonal and annual variability in pollutant loads within the waters into which those tributaries fed. However, the dynamics at play at a river’s mouth—the complex processes involved in the movement of chemicals and sediments from lotic (flowing) river to lentic (relatively still) lake water—had not been examined.

Sandusky Bay afforded the Lab an excellent opportunity to conduct such a study. The uniformly shallow bay (Figure 6) stretching some 20 miles and covering an area of 162 km² (62.5 mi²) is divided into upper and lower portions of sub-equal size by natural points of land extending from the north and south shores. The mean water depth of the bay had been listed on navigation charts as 1.6 m. However, during the four-year course of a $240,000 NOAA-supported study on the fate of pollutants carried by storm runoff into the bay, the Lab recorded a mean depth of 2.6 m with a corresponding volume of 422.5 million m³ (14.9 billion ft³). The movement of water into and through the bay and into the southwest corner of the Lake’s Central Basin proved to be strongly influenced by Lake level and seiche effects due to lake and bay winds, as well as by increased river flow following storm events.

Figure 6. The Sandusky Bay flows into the southwest corner of Lake Erie’s Central Basin. (Davis, T.W., et al. 2015)
Following on the Lab’s research on the transport of pollutants in riverine systems and its 2-year Nearshore Study aboard the R/V Simons, the plan was to investigate pollutant concentrations within a set of 25 sampling stations within the bay (and 9 stations in the lake just beyond) during two storm runoff events and two low flow periods during the summers of 1981-1983. Because of a paucity of storms, the study was carried on for another year but even so, the weather only allowed for monitoring of five storm events. The work was carried out on the Lab’s refurbished 36 ft cabin cruiser, the R/V McQuate.* For the purposes of the project, the lab grouped the chemical species of the study into five categories: nutrients (various forms of phosphorus, nitrite+nitrate), heavy metals and industrial organics, pesticides (nine forms including atrazine and alachlor), biological measures (chlorophyll, pheophytin) and conservative measures (chloride, specific conductance).

The study’s results supported the Lab’s initial predictions that most of the pollutant load entering the bay were associated with storm runoff and were of non-point origin, with point source loads being largely assimilated, under normal flow conditions, before reaching the bay. The bay itself proved to be an important region of pollutant assimilation. The slow-moving currents that predominated during most of the year allowed particulate pollutants to settle to the bottom of the bay, dissolved nutrients to be assimilated by its dense populations of phytoplankton, and pesticides to undergo degradation. Under average conditions, Sandusky Bay holds 80-100 days of the Sandusky River’s flow, and the report concluded that “the pollutant load to the lake is substantially less than it would be if the bay were not there…”

A biologist among the chemists: Ken Krieger’s diverse studies

Kenneth A. Krieger hired on with Dave Baker and Rock Prater in 1978 as a zooplankton and benthic invertebrate biologist, part of the Lab’s expanded staff working on the Lake Erie Intensive (Nearshore) Project. Ken had spent several years developing his collegiate teaching skills as a Visiting Professor at several institutions after having received his Ph.D. from Emory University in 1976. His wife Susan had wanted to be closer to her family in Michigan and it seemed that spending a couple of years at Heidelberg as a research biologist would round out his credentials, making him an attractive candidate for a more permanent position a bit further north.

Ken joined the staff and crew of the Roger R. Simons on its second cruise of the first year of the study. Thirty-two years later, he began the first of his six-year run as the sixth Director of the National Center for Water Quality Research. So it goes.

At the study’s conclusion, members of Prater’s team of biologists had to decide on their next career objective. Many joined Rock at AquaTech, the environmental company he established in Melmore. Phycologist Phil Kline stayed on at the Lab for a few more years before leaving for other opportunities. Prior to leaving, he and Ken established an Aquatic Biology

*Named for Professor Arthur McQuate, long-time chair of the Biology Department (whom Baker replaced in 1966), the 1968 Fairliner Sedan Fly Bridge Cruiser powered by twin 260 HP V8 Chrysler engines had been donated to the College by Donald Whitman. The vessel continued to be used for all-day student field trips as part of Ken Krieger’s Aquatic Biology course (BIO 3232) until 1986.
course which Krieger took over on Phil’s departure. This course was to be the first of what was to become Ken’s extensive teaching portfolio. From 1978 through 2014, Krieger taught courses at Heidelberg in Freshwater Ecology, Limnology (the study of inland waters) and Water Pollution Biology. During eleven summers from 1989 through 2002, he also taught or team-taught the graduate course in Limnology at The Ohio State University’s Franz Theodore Stone Laboratory on Gibraltar Island in Lake Erie.

Ken has shared his expertise on methods of habitat assessment and the identification and use of macroinvertebrates in monitoring stream and lake water quality in numerous workshops with researchers, students and volunteers. Along with his teaching responsibilities and his own research, from 1985-2002 Ken served as the College’s Director of Academic Grants, assisting faculty members from across campus to prepare grants in a wide diversity of fields of study. And from 2000-2004, he chaired the Gillmor Science Hall Building Committee, from its early planning stages through construction and occupation of the $4.7 million facility in December 2004. In recognition of his extensive research, pedagogy and service to the University, Heidelberg’s Board of Trustees took the unusual—and well-deserved—step in 2002 of granting Dr. Krieger status as Full Professor of the Faculty.

As an aquatic biologist with special expertise in the use of macroinvertebrates as bioindicators of environmental quality, Ken’s work would seem to compliment the Lab’s numerous water chemistry investigations. But although his studies were valued as an important component of the Lab’s overall research profile, only a minority of his biological research was conducted in concert with the Lab’s water chemistry studies. The Lake Erie Nearshore study for which he (along with a number of other biologists) was originally hired was the most obvious collaborative research effort. Another project supporting one of the Water Lab’s primary areas of interest was Ken’s four-year study (1982-1985) documenting the extent of conservation tillage adoption in the Rock Creek and Honey Creek watersheds. The study was conducted at an early stage in the State’s promotion of reduced and no-tillage cultivation as a means for reducing soil and nutrient inputs into area streams and rivers. Krieger’s survey of over 2,000 fields found low adoption rates with significant year-to-year variability in both watersheds (0-14% for soybeans and 0-6% for corn). This data set provided a useful baseline against which to compare high rates of adoption in subsequent years. (By 1994, conservation tillage would be used on 51% of corn and soybean acreage in Northwest Ohio.)

There were also several studies in the 1990’s, published under his name reporting on the Lab’s investigations of the effectiveness of coastal wetlands in removing agricultural pollutants from waters entering Lake Erie—this in association with his long-term studies at Old Woman Creek National Estuarine Research Reserve near Huron, Ohio. However, for the most part Krieger’s research program followed a separate trajectory from that pursued by the Lab’s water chemists and modelers. Ken has attributed Dave Baker’s willingness to allow him to pursue his own interests—within the Lab’s financial constraints—as a primary reason for the diversity and success of his numerous studies and for his family’s decision to remain in Tiffin.
Not forgetting that Dave Baker’s graduate degrees and early research were in plant physiology, following Phil Kline’s departure in 1979 and throughout the remainder of his career, Krieger was the WQL’s sole Ph.D. working primarily on biological topics. To a large extent, he compensated for the lack of in-house biological colleagues by training a highly-skilled cadre of undergraduate research assistants (a number of whom served as co-authors on various of his publications) and by developing an extensive network of collaborative relationships with researchers at other institutions and governmental organizations.

Typical of such fruitful collaborations is Ken’s 1988-89 study of the macroinvertebrate community in Cleveland Harbor, which he compared with his earlier study of the harbor conducted in 1978-79. Numerous employees of the Ohio EPA assisted in field sampling (conducted on an OEPA research vessel) at 12 stations within and outside the harbor in October 1988 and May 1989. Back at Heidelberg, an array of students under the supervision of WQL technician, Nancy Miller, worked over microscopes for some 2,100 hours in the tedious but essential task of picking and sorting invertebrates from preserved samples. In addition, Dr. Ralph Brinkhurst of the Institute of Ocean Sciences in British Columbia assisted with identification of oligochaete worms.

Of 75 taxa identified, 22 were oligochaetes, 16 were chironomids, and 11 were mollusks. Most of the harbor was underlain by highly organically-enriched sediments which were dominated by five tubificid worm species and pill clams (of the genus *Pisidium*), although the open water community, representative of less enriched conditions, was dominated by the tubificid *Limnodrilus hoffmeisteri* as well as *Pisidium* spp. and midges of the *Chironomus anthracinus* group. A dramatic increase in the number of taxa at all sites, a reduction in the proportion of oligochaete worms, a large increase in the abundance of sphaeriid clams and midge larvae, and the widespread distribution (though in low abundance) in open water sediments of caddisfly larvae, among other characteristics, suggested improvement in habitat quality within the harbor since the late 1970s.

One summer day in 1992, Ken was leading an aquatic field trip with his Limnology class at OSU’s Stone Laboratory. The morning’s work entailed sifting through mucky bottom sediments collected with an Ekman grab sampler from several locations in Lake Erie’s Western Basin, with the goal of introducing the students to the Lake’s benthic macroinvertebrate community. One of the samples contained a specimen that changed Krieger’s professional life for the next several years, but not as much as it changed the ecology of the Lake. It was a nymph of the genus *Hexagenia*, the aquatic larvae of a mayfly.

Until the mid-1950s, the nymphs of two species of burrowing mayflies, *Hexagenia limbata* and *rigida*, had been especially abundant in the sediments of the Lake’s Western Basin where they were a major food source for many of the fish species fed upon by recreationally and commercially important fish like smallmouth bass and walleye. Between 1930 and the early 1950s, *Hexagenia* densities in Western Basin sediments averaged 300-500/m². In the space of a
few weeks in June and July, massive numbers of nymphs would swim to the Lake’s surface to complete their life cycle, forming the primary food for many species of fish. In fact, from a fisheries point of view the Western Basin’s aquatic ecosystem was considered to be largely founded on benthic mayfly populations. On reaching the surface, nymphs molted into winged subimagos (subadult forms) that flew to shore where they molted a final time into imagos (reproductive adults). Regional newspapers of the 1940s and early 1950s regularly reported nuisance swarms of millions of subimago and imago mayflies covering north coast beaches, buildings and highways.

All that changed late in the summer of 1953. During the preceding decades, industrial, household and agricultural pollutants entering Lake Erie had been creating oxygen depletion conditions in the deeper waters of the lake’s Central Basin. However, the Western Basin’s shallowness (averaging under 30 feet depth) generally ensured that prevailing winds roiled its waters enough to provide adequate oxygenation for even its bottom sediments. But August of that year brought an extended period of calm winds causing benthic dissolved oxygen to drop below minimum threshold levels, resulting in near 100% mortality of the basin’s mayfly nymph populations. Almost overnight, and for the next four decades, what had been a benthic invertebrate-based food chain shifted to a largely pelagic (open water) zooplankton-based food chain.

The Great Lakes Water Quality Agreement of 1972 between the U.S. and Canada committed the two countries to reducing pollution in Lake Erie. Although Western Basin water clarity responded to resulting pollution control measures, burrowing mayflies didn’t appear to recolonize its bottom sediments until the late 1980s. By 1995, however, the public began to once more notice onshore swarms of mayflies and one year later newspapers from Toledo to Sandusky were again carrying stories about millions of mayflies causing problems along the north coast.

Krieger had initiated a series of studies investigating the resurgence of mayfly populations within the Western and Central Basins. Working with a team of researchers from other universities, governmental agencies* and a network of volunteers,** he documented changes in Hexagenia populations over the next two decades in a number of publications.33,34 Following the rapid recolonization of mayflies in the Western Basin by the mid-1990s, it was expected that Hexagenia would soon recolonize large regions of the Central and Eastern basins. An extensive sampling program from 1997-2005, however, revealed a more complex story. Although Hexagenia densities in the island area of the Western Basin reached densities up to 1,278 nymphs/m², Central and Eastern Basin populations never saw comparable population increases. In the Central Basin, after experiencing modest density increases to no higher than 48 nymphs/m² by 2000, Hexagenia were mostly absent at Krieger’s sampling stations from 2001–2005. Nymphs were found along a nearshore transect in the Eastern Basin at densities ≤382/m² in 2001 and 2002.

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*Don Schloesser of the U.S. Geological Survey’s Great Lakes Science Center in Ann Arbor Michigan was an important collaborator, especially in the early years of the mayfly studies.
**Ken established the “Mayfly Watch” group of 24 volunteer observers, from Huron to Conneaut Ohio along the Central Basin, that operated from 1997-99.
During a 2004 lake-wide survey, *Hexagenia* were found at 63 of 89 stations situated throughout the Western Basin but at only 7 of 112 Central Basin stations (all near the western edge of the basin) and was not found at all in the Eastern Basin. Oxygen depletion at the sediment-water interface and cool temperatures in the hypolimnion were considered the primary factors preventing successful establishment throughout much of the Central Basin. Based on the results of such long-term studies, Ken has persuasively argued that *Hexagenia* can serve as a useful biological indicator of lake quality where its distribution and abundance are limited by anthropogenic causes.

Krieger’s many years of research at Old Woman Creek National Estuarian Research Reserve —he was the first researcher to conduct a study there after it’s designation as a Reserve in 1980—led to numerous publications among which were a collection of pictorial atlases of the various macroinvertebrate groups encountered in its wetlands. The atlases, assembled with the crucial help of staff member Anne Stearns (2004-2008) and a number of Heidelberg student research assistants who served as senior or second authors for different taxonomic groups, provide invaluable guides to the identification and taxonomic classification of many macroinvertebrate species found throughout North America. The keys to the chironomid midges, mayfly larvae, aquatic true bugs, aquatic oligochaete worms, cladoceran water fleas and copepods have proven especially useful to non-specialists needing to identify samples of aquatic invertebrates and to students attempting to learn the details of macroinvertebrate identification.

![Image](image_url)

Figure 7. Representative front covers of two of the pictorial atlases of macroinvertebrates of Old Woman Creek NERR and State Nature Preserve, Ohio.

The enlarged, labelled photographs of the various species have facilitated the appropriate use of aquatic macroinvertebrates as bioindicators of environmental water quality. As of this writing, the collection of atlases is available at the Old Woman Creek website (http://coastal.ohiodnr.gov/publications) and is maintained by ODNR.
Regarding financing the Lab

The Esso Foundation funds provided by President William T. Wickham in 1967 in response to a proposal written by Dave Baker and Chemistry professor Tom Taylor allowed for the purchase of equipment and supplies needed to implement the ‘River Labs’ component of Baker’s Biology 101 Laboratory course. This $2,500 was not only the seed money from which the Water Lab would grow but also the progenitor of Dave’s perennial search for adequate funding to support the Lab’s expanding diversity of programs. Throughout its history, the Water Lab has depended almost exclusively on “soft money,” seeking grants from sources outside of Heidelberg to provide for salaries, fringe benefits, supplies, equipment, transportation and indirect costs.

Dave Baker’s first successful external grant for $47,650 to the U.S. Federal Water Water Pollution Control Administration in 1968 in support of the Flow Augmentation study provided for the hiring of Jack Kramer, the Lab’s first full-time employee. The NCWQR dates from the receipt of this grant in 1969. From that point onward, a large proportion of each WQL researcher’s time would be devoted to seeking financial support for their studies.

By the time of the Sandusky River Symposium in 1975, the Lab had received grants and contracts in excess of $375,000. Further demonstrating the Lab’s growing reputation for quality work, by the decade’s end it had obtained additional contracts totaling $238,000 from the U.S. Corp of Engineers’ for its Lake Erie Wastewater Management Study and $1,226,000 from the U.S. EPA for the Lake Erie Nearshore Study. Early in 1985, Baker reported that the Lab’s funding from government and private sources was approaching $5 million and four years later, on its twentieth anniversary, that sum had topped $6 million. At the Lab’s 30-year mark in 1999, total support for its research programs since its inception exceeded $10 million. During the decade of the 1990s, the WQL’s operating budget averaged $561,000 per year, with funding coming from researchers’ intensive pursuit of support from multiple sources including state and federal agencies, municipal governments, industries and nonprofit foundations.41

Though these sums attest to the Water Lab’s success at securing funds to support its research, finding the resources to maintain or expand long-term monitoring studies like its Tributary Loading Program became a chronic problem for Baker. Here’s Dave commenting on the issue in a 1987 Prospectus on the Lab’s Lake Erie Agro-ecosystem Program:42

Although the WQL has been uniquely successful in conducting detailed, long term large scale environmental research programs for agricultural watersheds, we have not done so with the benefit of long-term funding. Instead we have been successful in obtaining a continuing series of short-term grants.

The WQL has developed a very broad base of both agency and industrial support, such that the contributions from any one group can remain relatively small in relation to the usefulness of the overall program. Support has been received from the Army Corps of Engineers, four different U.S. EPA programs, the Soil Conservation Service, the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, the Ohio Sea Grant Program, 10 different pesticide manufacturers, a consortium of electric power companies, detergent manufacturers, state agencies and two foundations.
And again in the Lab’s Annual Report for 1990: 43

Long-term and detailed monitoring is an essential ingredient for advancing the science of nonpoint pollution control for both surface and ground water. We have yet to identify enough sources of support for this vital aspect of our program. Consequently, we will have to devote a larger portion of our time to solving long-term funding issues during the coming year.

Similar comments may be found in Baker’s writings throughout the tenure of his time as Director. A fascinating example of his efforts to secure a more solid financial basis for the Lab’s long-term studies is a $2 million proposal to the Ohio Department of Development’s (ODD) Thomas A. Edison Fund for Expansion and Development submitted in March 1986. If funded (it wasn’t), the proposal would have established the Edison Environmental Research Center (EERC) at Heidelberg which would focus on the relationship between food production and water resources. In particular, it would explore the impacts of Northwest Ohio row crop agricultural systems on surface waters and groundwater in a set of 8-10 area watersheds as an ongoing case study evaluating the effects of various agricultural practices on water quality.

The far-reaching proposal would have entailed the construction of a dedicated research facility at Heidelberg and involved the participation of staff and graduate students from Bowling Green State University, Kent State University, Miami University, Oberlin College, Toledo University and the Ohio State University. Representatives of industries, agribusiness, federal, state and local governmental agencies and public sector groups would participate on advisory and review committees in helping to direct the EERC’s research activities and in disseminating useful insights developed from its studies. It was expected that industry and federal research support would increase from $400 to $1 million/year (or even higher with additional support from major foundations).

The ODD rejected Heidelberg’s proposal in July on grounds that it did not meet criteria provided by the Edison Board. The EERC proposal, it was claimed, would not lead to the creation of an appreciable number of new job opportunities in Ohio.* The Board thus discounted Baker’s argument that helping farmers adopt improved management practices would enhance their profits while decreased agricultural pollution entering Lake Erie would benefit the North Shore’s fishing and tourist industries. The proposal, however, had engendered wide support from universities, area businesses and local governments. Vern Riffe, then Speaker of the Ohio House of Representatives and Fremont Representative Dwight Wise, in particular, played an important role in encouraging Governor Richard Celeste to consider other options for funding the Lab’s work. In July Celeste created a Task Force of the Directors of the ODNR, OEPA and the Departments of Agriculture and Development to consider how the State might be able to help fund the WQL’s studies.

In the end, although Baker’s EERC was not funded, his proposal indirectly led to some $640,000 in support of the WQL’s programs. In a luncheon at Heidelberg44, Speaker Riffe announced that the Lab was to receive $140,000 which was being transferred from the budget of the Ohio Board of Regents in addition to $450,000 from the ODNR and $50,000 of Sea Grant

*An article in the Aug 16, 1986 Clyde OH Enterprise stated the ODNR (Administrator of the Edison Fund) rejected the proposal because it felt the Lab’s high level of computerization would create too few jobs.
funds that was being routed to Heidelberg through a block grant to the City of Tiffin. The support not only helped the Lab maintain its core functions but enabled it to update its technology and expand into new areas of study, including extending its pilot well water-water testing program into four Northwest Ohio counties. At least as important as obtaining these funds, establishing a positive working relationship at the highest levels of State government was to prove invaluable—an important step toward the State’s eventual earmarking of funds in its annual budget to support the Lab’s water quality studies.

Overall, the Water Quality Lab had been doing remarkably well during the 1980’s. The same could not be said for its home institution, Heidelberg College. For a variety of reasons, enrollments had markedly fallen during the latter half of the 1970s and the College’s financial picture was bleak; a number of faculty members lost their positions and the Art Department was eliminated. In 1980, the Board of Trustees hired William C. Cassell as Heidelberg’s eleventh President, providing him with a mandate to do what was necessary to turn things around. Under the previous Administration, the College had not been operating under budgetary control and Cassell’s first move was to put the institution on a strongly enforced budget.*

All areas on campus were required to do their part in helping the institution get back on its feet. Under such circumstances it is no surprise that the Water Lab, with an annual income by the late 1980s well in excess of $500,000, would engage the President’s attention. Cassell required full indirect costs on the Lab’s salaries, wages and fringe benefits of 59%, which commonly put the Lab’s budget in the red with a deficit to be carried into the following fiscal year. Baker has observed that at this time, most of the grants available to the WQL provided little or no allowance for indirect costs, placing the Lab in a difficult bind.

Fiscal year 1990-1991 represented a turning point in this situation. During the College’s annual audit, Cassell directed the auditor to pay special attention to the Water Lab’s budget and to Heidelberg’s costs in maintaining the Lab. The President was exploring, Baker recalls, whether the College could reasonably require a higher annual contribution from the Lab. The auditor’s report, however, indicated that compared to similar university-based research facilities, the WQL was already paying Heidelberg roughly five times as much as it should and recommended that indirect costs be significantly lowered. Administration followed the auditor’s recommendation and the subsequent reduction in the Lab’s indirect costs from $150,000 to $35,000 per annum enabled the Lab to eliminate its problems with unbalanced budgets.†‡

**The Water Quality Laboratory at thirty looks to the future**

In 1997, David Baker visited his doctor to address a severe reaction to a mosquito bite he’d been dealing with. In short order he discovered the abnormal immune response stemmed not from a new allergy but from a form of lymphoma, chronic lymphocytic leukemia. Although

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*Bill Wickham, longtime Chair of the Business Department, personal communication.
†David Baker, personal communication
‡As discussed in Chapter 5, this was raised to $72,000 per annum beginning with the 2019-2020 fiscal year.
Dave claims to have never felt that badly, by the start of 1999 his white blood cell and platelet counts had plummeted, chemotherapy trials were initiated, and his energy level and ability to concentrate had fallen off. In June 1999, Baker retired after thirty years serving as the Lab’s founder and first Director. Of course Dave’s retirement, in large part, was precipitated by the need to confront his cancer with much the same focus with which he had addressed the myriad challenges of his long professional life. But he also felt that after three decades, the Lab could “use some new blood.” In truth, this was the tip of an iceberg that would soon require attention as the core of the WQL team—Jack Kramer, Ellen Ewing, Barb Merryfield, Pete Richards and Ken Krieger—had each been with the Lab almost as long as Dave.

With the assistance of a competent team of physicians, adherence to an immunoglobulin therapy regimen and, most especially, the vigilant attention and loving support of his wife, Peg, Dave’s retirement would thankfully prove to be temporary. But 1999 was the year that ushered in the first of many transitions in staffing, financial arrangements and research perspectives that Heidelberg’s Water Lab would need to weather in the coming decade. So this seems a good point to consider how Dave’s leadership and vision had positioned the Laboratory for the new century.

Any attempt to present a concise (and readable) review of the WQL’s numerous and varied projects, for even just its third decade, would face significant challenges; there was so much going on—so many samples being collected and analyzed, reports and papers published, professional and public presentations, workshops conducted, grants prepared and received, courses taught, and student research mentored. However, it seems that under Dave’s direction the Lab primarily developed expertise in two interrelated and complementary areas of activity: comprehensive studies of the impact of agriculture on water quality and environmental education. The Laboratory’s Mission Statement, as presented in the eight Annual Reports Baker prepared between fiscal years 1989-1990 and 1996-1999,* illustrates this dual commitment to research and education:

*After a hiatus of 13 years, Ken Krieger reinitiated the Annual Reports, producing five during his tenure as Director, from 2010-2011 through 2014-2015.
the general public. We endeavor to support enlightened management of the state’s and nation’s soil and water resources through providing accurate assessments and perspectives on issues related to agriculture and the environment. Our educational mission is also expressed through work with undergraduate students in Heidelberg’s Water Resources Major, with graduate students from state universities, and with teachers and students from area high schools.

A. Research on the impact of agriculture on water quality. In the late 1980s, Dave saw the value of laying out his thoughts on the WQL’s primary research objectives as a means for communicating, both to the scientific community and the general public, the Lab’s focus as a water research facility within the Lake Erie watershed. In 1987, he prepared a prospectus on what he identified as the Lake Erie Agro-Ecosystem Program (LEAP) centered at Heidelberg’s Water Quality Laboratory. In the Background section of the Program Summary, he wrote:

The Lake Erie Agro-ecosystem Program (LEAP) provides a framework for both assessing and supporting programs aimed at reducing the adverse impacts of row crop agriculture on this region’s water resources. At the same time, LEAP can yield significant advances in the basic understanding of land-use/water quality interactions.

This synopsis signaled a shift in orientation that had emerged as the Lab matured from its early years of developing its water quality monitoring procedures to a growing interest in applying its monitoring skills and data to playing an active role in helping improve area water quality. Although the LEAP acronym would cease be seen in WQL communications by the mid-1990s, the 12 Program Objectives listed in the prospectus would continue to underpin much of the Lab’s approach in designing, conducting, interpreting and communicating its studies. The Objectives listed in the Prospectus were to:

1. assess the effects of changing agricultural technology, including the adoption of best management practices, on agricultural pollution in Lake Erie and its tributaries.

2. assess potential regional water quality trade-offs that may be associated with agricultural pollution abatement programs, such as the possibility that by decreasing surface runoff of pollutants, ground water pollution might be increased; or that by controlling erosion with conservation tillage, herbicide runoff might be aggravated.

3. assess and improve the effectiveness of critical area targeting as a component of regional agricultural pollution abatement programs.

4. develop techniques for detecting management-related changes in water quality in the presence of extensive variability caused by variable weather conditions.

5. increase the scientific understanding of the movement of both soluble and particulate substances to and through river systems.

6. assess the relationships between watershed size and stream water quality, as impacted by land runoff and baseflow.
7. provide a “data rich” environment for the development, calibration, verification and evaluation of models used for estimating the impacts of agricultural land use on water quality and predicting regional water quality responses to proposed management programs.

8. assess the impacts of agricultural nonpoint runoff, including pesticides, on biological communities in stream systems.

9. support agricultural pollution abatement implementation programs through effectively conveying information regarding the extent and significance of agricultural nonpoint pollution, as it is currently understood, to farmers and the general public.

10. provide accurate pollutant loading data for the major tributaries emptying into Lake Erie, as mandated in the Great Lakes Water Quality Agreement and the Lake Erie Surveillance Plan.

11. accurately assess the impacts of agricultural nonpoint pollutants on Lake Erie water quality, relative to impacts of pollutants from other sources.

12. establish and refine a model program for large-scale, long-term agricultural ecosystem studies.

In 2002, the Journal of Environmental Quality published a “Special Submissions” section of 11 articles on the findings of the USDA-sponsored Lake Erie Agricultural Systems for Environmental Quality (LEASEQ) project, a retrospective consideration of the effects of governmental and other changes in agriculture on soil and water quality within the Maumee and Sandusky watersheds during the 21-year period from 1975-1995. Heidelberg’s Pete Richards and Dave Baker were lead or contributing authors in five of these papers. The LEASEQ team also included researchers from Case Western Reserve and the Ohio State Universities.

In the final paper of the series, Baker and Richards observed that annual phosphorus inputs to the two watersheds’ soils during this time period had decreased (due to farmers’ reduced use of fertilizers), with declines in net soil accumulation of phosphorus from 13.4 and 9.5 kg/ha/yr to 3.7 and 2.6 kg/ha/yr for the Maumee and Sandusky watersheds. Additionally, riverine export of total phosphorus (TP) decreased by 25-40% and soluble reactive phosphorus (SRP) decreased by 60-89%. They suggested these encouraging trends in reduced phosphorus export were likely associated with farmers’ adoption of conservation practices that minimized surface runoff of recently applied fertilizers and sediments, coupled with reduced snow cover and increased minimum winter temperature which, together, reduced winter stream flows in the region.

The optimistic perspective underlying this analysis, that the environmental factors impacting water quality conditions in Lake Erie had notably improved since the dark days of the early 1970s when the lake had widely been declared “dead”…was somewhat premature. Given available data, the assessments of largely positive changes in soil and water quality following the adoption of conservation tillage and other modifications in farmland management voiced in the various LEASEQ papers were entirely reasonable. However, as discussed in the Primer on Phosphorus section of Chapter 1, the resurgence of severe algae and cyanobacteria-related problems within the lake during the following decade would in part prove an unanticipated side-effect of the widespread adoption of these same agricultural practices. Bringing to light the
surprisingly complex relationships between land management practices and water quality would constitute a significant component of the Lab’s research agenda during the next two decades.

B. Environmental education. The seed for the National Center for Water Quality Research was planted when, a year after his arrival at Heidelberg in 1966, an idea occurred to David Baker for a way to enliven his freshman biology laboratories with a taste of real-world research. The River Labs sequence beginning with the fall semester of 1967 (and continuing for five years) not only introduced hundreds of students to how science is conducted but generated the initial data sets that would open Dave’s eyes to the potential for conducting meaningful water quality research on the Sandusky River. Over the next five decades, the Lab’s educational objectives—for students, the scientific community, policy makers and the general public—would remain an important and growing component of its charge to itself.

Baker’s first major grant at Heidelberg—$47,650 from the Federal Water Pollution Control Administration for the Flow Augmentation Study—not only provided the funding to hire Jack Kramer as the River Lab’s first full-time employee, but also enabled Dave to initiate what was to become a long-standing tradition of hiring part-time Heidelberg students as research assistants. By 1972, students whose appetite had been whetted for further research opportunities could participate in “Research in Aquatic Systems” labs, in which they helped analyze the River Lab’s burgeoning mass of data.

For 4-5 years in the early 1970s, Heidelberg students were successful in obtaining a series of grants through the National Science Foundation’s (too short-lived) Student-originated Grants Program. Students wrote and submitted the proposals, recruited other students to work on their projects and administered and reported their results back to the NSF. They studied a wide diversity of aquatic research topics ranging from riverine phosphorus transport to macroinvertebrate and clam distributions within the Sandusky.

The Water Lab’s close association with Heidelberg’s Biology and Chemistry Departments was soon reflected in the College’s science curricula. In 1975 the Biology Department added Aquatic Ecosystems (BIO 323)—the first of a series of water-related courses—to its list of offerings. Two years later, when Heidelberg added the Environmental Biology major to its catalog, it also created a follow-up course to BIO 323, Water Quality Analysis (BIO 324). In 1993, the College introduced its new Water Resources major, one of the few majors in the nation devoted to preparing students for the growing demand for water resource managers and scientists. The interdisciplinary major included a strong core of General Chemistry and Physics, Calculus, Elementary Statistics, Physical Geology and six new courses in water studies: Water Pollution and Analyses (WTR 205), Limnology (WTR 323), Hydrology (WTR 352) and a two-semester sequence in research, Research I (WTR 392) and Research II (WTR 393) as well as a Water Resources Seminar (WTR 422). In addition, students were required to complete coursework in one of three tracks: Biology, Chemistry or Geology.

*Its title was changed to Aquatic Biology in 1977.
†Its title was changed to Environmental Science in 2008.
In 1995, Heidelberg received a $49,992 grant from the Ohio Environmental Education fund (OEEF) in support of a two-summer planning sequence to restructure a set of courses in the newly created Water Resources major so as to support the WQL’s long-term watershed studies. The central focus of the “Integrating Interdisciplinary Water Resources Studies Around the Curriculum-based, Long-term Watershed Studies (CLWS)” model was to incorporate a series of water quality measurements in area rivers and streams into various Water Resources courses which, when taken together, would provide high-quality data that would contribute to the WQL’s Tributary Loading Program and others of its long-term research objectives. The concept of integrating the College’s Water Resources major with the Water Lab’s watershed research programs was vintage David Baker. The CLWS grant not only supported efforts to involve Heidelberg WTR majors in real-world, goal-directed research, but it also developed two workshops for high school and junior high school teachers to help them offer appropriately designed aquatic research experiences for their students.

After a promising start, the CLWS program largely faded from the picture. The heavy teaching demands on the biologists, chemists and geologists who had participated in the initial planning sessions generally made it too difficult for them to incorporate student research activities of adequate rigor to be of value in the WQL’s studies into their courses. In fact, although Water Resources had attracted 20 majors by 1999, it was never able to live up to the school’s expectations for recruiting a large number of students and Administration eliminated the major in 2008.

Heidelberg’s frustrating inability to attract the numbers of majors one might expect for a student-oriented liberal arts institution housing one of the nation’s top water research facilities was the topic of discussion in numerous program reviews, committee meetings and over innumerable cups of coffee. Perhaps it was a function of the college’s small size or its location in a small town at some distance from Ohio’s major cities. Perhaps it was the tuition rate, student housing options, ineffective marketing or the unfamiliarity of the term, “water resources.” Certainly, with all the other excellent small private and large public institutions in Ohio from which to choose, there was no lack of competition for high school students interested in environmental careers.

Even so, as of 2018, Heidelberg’s Environmental Science major (and its Environmental Studies minor) continued to attract strong students interested in water quality issues. With newer courses in Geographical Information Systems (GEO 250), Surface Water Systems (GEO 308), Soils and Groundwater (GEO 350), Biostatistics (BIO 205) and Environmental Chemistry (CHM 205) along with expanded opportunities to work as research assistants in the NCWQR, the University was still offering a solid grounding for undergraduates in the study of water quality. In 2019, Heidelberg’s faculty approved the restructuring of its Environmental Science major into the Environmental Science and Sustainability major and the creation of a new Watershed Studies Specialization. Both programs were designed to better incorporate NCWQR staff members in teaching within the University’s undergraduate curricula and are discussed further in Chapter 5.
The other central piece of the Lab’s education agenda is its long-standing Environmental Extension program, a term first applied to staff speaking engagements before general audiences (as separate from presentations at professional meetings and workshops) in 1991. Between January of that year and March 1992, Dave Baker, Pete Richards, Ken Krieger and Laura Wallrabenstein (Quality Assurance Coordinator for the Lab, 1987-1995) gave 80 presentations to groups as varied as the American Farm Bureau Federation, Monsanto Dealers’ workshop, the Huron River Advisory Group, Fremont Kiwanis and a sixth grade Environmental Field Day in Republic Ohio. Throughout the rest of the decade, the Lab’s staff typically presented 50-60 environmental talks, seminars and workshops per year.

In August 1997, the WQL hosted what was to prove a particularly important meeting for citizens interested in the health of the Sandusky River. Representatives of the agricultural community, environmental groups and governmental agencies met to discuss the creation of the Sandusky River Watershed Coalition (SRWC). The Coalition, which held its first meeting on September 18, set its primary functions to:

1. create an inventory of the watershed by assessing the quality of ground and runoff water; 
2. examine human and ecological features that affect water resource quality; and 
3. provide a coordinated mechanism, based on real world management problems, to apply for and acquire management funds to deal with those problems.

As illustrated in the Management Development Plan, in Figure 8, the Coalition also sought to “garner support for—and participation in—the diverse programs aimed at protecting and enhancing the water resources of the Sandusky River Watershed.” By the early 2000s, Coalition members had grouped into Agriculture, Wastewater, Water Supply, Stream Flow & Nutrient, Development and Education Committees, each with their own set of Goals and Action Items. Funding for the Coalition would come from state and federal grants and support from individuals and member organizations, while most of the Coalition’s work would be performed by volunteers. In 2017, the organization and direction of the SRWC was transferred from the Great Lakes Community Action Partnership (formerly the WSOS Community Action Commission) to the NCWQR.
The communication of information has always been a central facet of the Water Lab’s *modus operandi*. From its roots in Baker’s Introductory Biology River Labs sequence to the present day, sharing of what the Lab’s researchers have learned about the interface between agricultural land practices and water quality within area watersheds has been one of the Lab’s foundational principles. In the 2000s, a grant from the Lake Erie Education Fund (LEEF) enabled the Lab to make its long-term Tributary Loading Program data freely available, online, to any interested party. The continuously updated website is provided with a set of tutorials to assist researchers, educators and others in how to explore the information provided which, as of 2019, includes the Lab’s data on 25 watersheds (https://ncwqr.org/monitoring/data/). An important feature of the website is its analytical template—a downloadable macro-based Excel program that facilitates graphical exploration of the river data sets as well as automating tabular summarizations. The program was written by Mark Baker, Dr. Baker’s son who received an MS in Civil Engineering, specializing in Hydrology from the University of Michigan.

Another example of a freely available online resource is its periodically updated Best Management Practices (BMP) Toolbox, another LEEF-supported website developed to provide information and a framework for discussion on ways to reduce dissolved phosphorus runoff from croplands into Lake Erie (https://ncwqr.org/resources/).

In addressing the commonly posed question of how it came to be that this state-of-the-art water research facility came to exist within the setting of a small liberal arts college in Tiffin, Ohio, Dave Baker would often respond by saying, “In many instances we were in the right place at the right time with the right people.” That concise and truthful statement neatly sidesteps the more fundamental question of how it was that the right people were there and ready to step up to the enormous task involved in initiating, maintaining and expanding the focus of the Lab’s diverse studies. In interviews with Jack, Ellen, Barb, Nancy, Pete, Ken and other staff members
from the first 30 years of the Lab’s existence, the universal answer to that question singled out Dave’s drive and vision as the principal engine underlying the Lab’s longevity and its impressive string of successes. How the Lab addressed changes in leadership and direction with his retirement in 1999 is the principal topic of the next chapter.

16 Murphy, S. Oct. 9, 2002. Tentative deal reached in suit over 1988 spill. The Toledo Blade,


Chapter 4. The NCWQR under Five Directors, 1999-2015

David Baker directed the Water Lab from its founding in 1969 until his (first) retirement in June 1999. Initially named the Sandusky River Project, the Lab morphed into the River Studies Laboratory in 1976 and the Water Quality Laboratory in 1978. After thirty years under his guidance, the Lab was finally entering the long-awaited period of transition to the next generation of leadership.

<table>
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R. Peter Richards, 1999-2002

Of Peter Richard’s many and varied interests—geology, crystal mineral structure, statistical trend analysis, computer programming, watershed modeling and singing, to name a few—he would not have placed directing the Water Quality Laboratory high on the list:

When it became clear in 1999 that Dave’s health would not permit him to continue as Director, the most logical option for the Lab seemed for me to succeed him, at least temporarily. It was a struggle for me as I tend to view myself more as an active follower than someone given to planning and looking to the future. I was OK handling the financial books and acting as the “face of the lab,” but following up on the abundance of complex tasks that had to be addressed was very stressful.

On assuming the Directorship, Pete was already 29 years past receiving his Ph.D. in Paleoecology from the University of Chicago. It was clear he would not hold the position for too many years before retiring himself and no small part of his agenda would be to find his replacement from outside the Heidelberg community of researchers. And with that new Director would surely come new perspectives, priorities, and directions for the Lab—prospects both exciting and frightening in equal measure.

Staff members working during Richard’s three-year Directorship observe that he handled his numerous responsibilities well and that the Lab largely continued as it had before Baker’s retirement. A review of the publications, reports and presentations prepared during the period suggests the Lab’s research team, while carrying forward with its long-term studies like the Heidelberg Tributary Loading Program (HTLP), felt the time was ripe to take stock of what they had learned over the past several decades of investigation.
In the section titled *The WQL at thirty looks to the future* of the preceding chapter, reference was made to Issue 31 of the 2002 Journal of Environmental Quality, which contained a compendium of 11 articles addressing changes in soil and water quality within the Maumee and Sandusky watersheds during the 21 years from 1975-1995. The papers presented the principal findings of the USDA-sponsored Lake Erie Agricultural Systems for Environmental Quality (LEASEQ) project and, inasmuch as Richards and Baker were lead or contributing authors in five of these papers, the issue also summarized much of the Water Lab’s understanding, at the start of the new century, of the complex interface between agricultural practices and water quality within the two basins.

The review’s approach was to evaluate how each of the compartments of the Lake Erie agroecosystem comprising these two watersheds (Figure 1) had changed over the past two decades, with special focus on whether changes in agricultural management practices might have had beneficial effects on the various outputs of the agroecosystem. The Maumee and the Sandusky rivers had been selected for this study because they are the two largest U.S. tributaries* to Lake Erie—with watersheds of 16,205 sq km (6,257 sq mi) and 3,202 sq km (1,236 sq mi), respectively—and because the WQL’s monitoring near the outlets of these two rivers between 1974 and 1995 contained data from 8,343 samples for the Maumee and 9,416 samples for the Sandusky.

![Figure 1. Changes in the Lake Erie Agroecosystems of the Maumee and Sandusky River watersheds, 1975-1995, were examined during the LEASEQ project. (Richards, R.P. et al., 2002)](image)

In discussing their observations of changes in nutrient concentrations during the two decades of the LEASEQ study within the Maumee River, Sandusky River and two tributaries to the Sandusky (Honey and Rock Creeks), Richards and Baker² reported substantial decreases in total and soluble reactive phosphorus at all study sites (29-58% decreases in TP, 72-88% decreases in SRP). Smaller but highly significant decreases (14-57%) in total Kjeldahl nitrogen (TKN) were also documented at all stations while significant decreases (18-53%) in total suspended solids were documented for the Maumee, Sandusky and Rock Creek. Nitrates did not

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*Setting aside the Detroit River draining Lake Huron and the Upper Great Lakes.
show significant trends at the two stations draining major watersheds but showed significant trends in opposite directions at the two stations on the smaller watersheds (increased in Honey Creek, decreased in Rock Creek). Additional analyses suggested that changes in fertilizer and manure application rates were the most important cause of trends in phosphorus and TKN, and that point sources were insufficient to account for the phosphorus trends.

In a study of phosphorus budgets within the two watersheds, Baker and Richards found that annual P inputs decreased due to reductions in fertilizer and manure application while annual outputs increased due to increasing crop yields. Overall, net P accumulation on farm lands decreased during the two decades from peak values of 13.4 and 9.5 kg P/ha/yr to 3.7 and 2.6 kg P/ha/yr for the Maumee and Sandusky watersheds, respectively. Even though the rate of phosphorus accumulation had decreased over the 21 years, it remained positive and the substantial reductions seen in SRP export in both river systems was unexpected.

The large decreases in SRP export were not anticipated at the time the Lake Erie phosphorus control programs were initiated. Pilot studies at that time were showing increased SRP export with no-till systems, due to buildup of phosphorus levels in the surficial layers of the soil. … In this region, with the large clay content of the soils, tile effluent has very low SRP concentrations. The authors suggested decreases in TP and SRP export were associated with farmers' adoption of practices that minimize transport of recently applied P fertilizer and of sediments via surface runoff, coupled with changes in winter weather conditions. A separate review of agricultural trends within the two watersheds seemed to support this view.

Conservation tillage increased from virtually nothing to nearly 50% of cropland in corn (Zea mays L.) and soybean [Glycine max (L.) Merr.]; most of the change is due to adoption of no-till soybean. … Cropland in soybean had increased; land in wheat (Triticum aestivum L.) and hay has decreased. Cropland in corn has decreased in the Maumee watershed and increased slightly in the Sandusky watershed. … Fertilizer phosphorus sales increased until about 1980 and have declined significantly since then; fertilizer nitrogen follows a similar but less pronounced pattern. The decreases are more substantial in the Maumee watershed than in the Sandusky. Manure use for fertilizer has also declined significantly.

The generally optimistic outlook voiced in the eleven LEASEQ project reports of this 2002 Special Supplement to the JEQ had been based on a detailed set of studies that concluded in 1995. This was somewhat ironic timing as by the mid-1990s, the Water Lab’s continuing studies were showing the Maumee and Sandusky were once again starting to see increased SRP export, and the first algal blooms in over 10 years were being reported in Lake Erie’s Western Basin in 1995 and 1998. As would be noted in numerous future publications, largely unanticipated consequences of the same widely adopted soil-conservation best management practices (BMPs) within the Maumee watershed that had so helped to improve water quality in the river and the Lake, were beginning to play a pivotal role in the resurgence of HNABs through their effect on the transport of bioavailable phosphorus into and through the Maumee River.

Ken Krieger, while continuing with his various macroinvertebrate studies in Cleveland Harbor, Old Woman Creek and Lake Erie, was also looking back on his work during the previous decade. As noted in Chapter 3, A Biologist among the Chemists, Ken had developed a
network of working relationships with researchers from other universities and governmental agencies in documenting the recovery, during the 1990s, of *Hexagenia* mayfly populations in Lake Erie’s Western and Central Basins after their virtual disappearance in the mid-1950s. In a 2000 paper co-authored with colleagues from the USGS and the University of Windsor, Canada, the mayflies’ recovery in the Western Basin to that point was summarized:

Nymphs were absent or rare in the basin between 1961 and 1973–1975. In 1979–1991, nymphs were infrequently found (13–46% of sites) in low abundance (3–40 nymphs/m²) near shore (<7.5 km from shore) but were absent or rare offshore (0–7% of sites at 0–1 nymphs/m²). Increased abundance occurred offshore between 1991 (0% of sites) and 1993 (52% of sites at 7/m²). Annual sampling, beginning in 1995, indicates that nymphs increased in both nearshore and offshore waters. By 1997, nymphs were found throughout the lake (88% of sites) at a mean density 40-fold greater (392/m²) than that observed in 1993 (11/m²). In 1998, the distribution of nymphs remained the same as 1997 (88% of sites) but density declined 3-fold (392 to 134/m²). These data indicate that mayflies have recolonized sediments of western Lake Erie and that their abundance may be similar to levels observed before their disappearance in the mid-1950s. However, prior to the mid-1950s, densities were greater in offshore than nearshore waters, but between 1979 and 1998 greater densities occurred near shore than offshore.

In February 2002, he hosted a workshop at Heidelberg on refining and implementing the mayfly (*Hexagenia*) metric of the Lake Erie Quality Index he had helped develop.

In March 2000, the WQL hired Sabine Grunwald as a Research Scientist and GIS Manager. Sabine’s Ph.D. from the University of Glessen, Germany and her subsequent employment and Post Docs had provided her with many of the tools the Lab had been looking for to extend its studies into landscape modeling. Unfortunately, the Lab’s expectations of her responsibilities and Grunwald’s expectation of research opportunities afforded by the Lab did not make for a comfortable fit and Sabine left the WQL in July 2001. At this writing, she was a Professor in the Soil and Water Sciences Department at the University of Florida.

**Timothy T. Loftus, 2002-2005**

After a protracted national search, landscape ecologist Tim Loftus was hired as the Water Lab’s first Director from outside the Heidelberg circle of researchers. Tim’s Ph.D. work at Southern Illinois University at Carbondale led to a series of collaborations with geographer Christopher Lant and agribusiness economist Stephen Kraft (both then at SIU) addressing soil and water conservation and watershed planning topics in the Midwest. On the one hand his familiarity with rural economics and the elements of watershed modeling were appealing assets as the WQL was interested in ways to facilitate linking water quality science and agricultural practices within the Maumee and Sandusky watersheds. On the other hand, his minimal experience with the day-to-day operation of an analytical chemistry lab was problematic.

In late spring 2005, Loftus was called into the office of the Vice President for Academic Affairs and told the unexpected news that his contract was not being renewed. These few details on the two bookends to his three years with the Water Lab—his hiring as the Lab’s first Director from “outside” and his unceremonious removal from that position—may be the only points upon
which his supporters and detractors within the Lab are in close agreement. Dave Baker, Pete Richards and Ken Krieger worked with Tim fairly well and thought he tried hard to advance the work of the Lab. Analytical Chemist Josie Setzler (1997-2006) saw a lot of value in what he was able to accomplish during his tenure as Director. Loftus, for example, played an important role in helping secure Congressional earmark funding enabling the Lab to purchase an Inductively Coupled Plasma-Mass Spectrometer (ICP-MS), greatly enhancing its metals detection abilities.

Tim himself felt he left the Lab in better financial shape than when he arrived, especially through his strengthening of State support for Heidelberg’s Tributary Monitoring Program. He counted among his most significant contributions the development of a Three-year Strategic Plan, helping to reverse a negative trend in the Cooperative Well Testing Program and overseeing the Lab’s relocation from the basement of Bareis Hall to the top floor of the newly constructed Gillmor Hall.*†

As Administrative Assistant to the Director, Nancy Miller agrees that the caliber of the Lab’s work did not suffer under Loftus and that he did a reasonable job on the critical task of overseeing the budget. But she also concurs with Jack Kramer, Ellen Ewing and Barb Merryfield that there was a striking disconnect between the Ph.D. researchers’ experience with Tim’s leadership and that of the chemistry lab technicians. There was a general consensus he would have preferred to have had his own team running the Lab in place of them and that there was a special level of friction between Tim and Jack which soured a work environment that had for decades been one of the WQL’s chief attributes. Unsurprisingly, Loftus sees things differently:

I am aware that some of the staff complained about various decisions I made and there was hurtfulness on both sides of those issues. I don’t know how much, if at all, that played into Administration’s decision to not renew my contract. In any case, I was not expecting to be let go when VPAA deAbruna called me into her office to say they “wanted to move the Lab in a new direction.” I do think it likely that I misplayed the politics of my situation with the Board of Trustees by not being accommodating enough to some of their ideas about what I should be doing as Director.

However polarizing some of the interpersonal relationships may have been during these years, some of the Lab’s most important work was produced during the period. As of this writing, for example, ResearchGate reports 262 citations of the 2004 paper introducing the Richards-Baker Flashiness Index. Baker, et al.8 observed that the term “flashiness,” as applied to stream flow, reflects “the frequency and rapidity of short term changes in streamflow, especially during runoff events.” It is influenced by such hydrologic features as variability in flow from day-to-day, frequency of flooding, magnitude of flood peaks, rate of flow recession following flood events and the amount of time that mean discharge rate is exceeded.

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*Gillmor Hall was dedicated on April 16, 2005. Cost overruns required a reduction in the building’s footprint from the original plans, resulting in all manner of problems in repositioning the Lab’s equipment.
†On leaving Heidelberg, Tim spent ten years with the Chicago Metropolitan Agency of Planning after which he moved to Texas where, at this writing, he is the Chief Conservation Officer, Professor of Practice in Geography and Meadows Endowed Chair in Water Conservation at Texas State University at San Marcos.
Changes in land management practices can lead to both short and long-term alterations in stream flow patterns with the potential for influencing a stream’s hydrologic, chemical and biological properties. Also, streams may vary widely in their flow rate characteristics as indicated in Figure 2 of the hydrographs of two rivers with similar drainage areas and precipitation patterns.

Figure 2. Hydrographs of the Portage River displaying marked flashiness from late-winter through early-summer, 2000 and the South Branch of the Au Sable River displaying a constant flow regime. (Baker, D.B., et al., 2004.)

The Portage River, with numerous storm runoff peaks, high peak flows but an otherwise low base flows is a much flashier stream than the Au Sable with its higher base flow and broader, flatter storm runoff peaks. The two lines tracing the hydrographs on this figure, if stretched out straight would differ markedly in total “pathlength.” The Richards-Baker (R-B) Index of flashiness is a modification of an earlier index developed by Richards that divided a hydrograph’s pathlength by the stream’s median daily flow and the study period.

The R-B index simplified the Richards Index by dividing the pathlength for a given sampling period—measured as the sum of the absolute values of day-to-day changes in daily discharge volume (or mean daily flow)—by the total discharge volume (or sum of mean daily flows) during that sampling period:

\[ R - B \text{ Index} = \frac{\sum_{i=1}^{n} |q_i - q_{i-1}|}{\sum_{i=1}^{n} q_i} \]

where \( q \) can be either daily discharge volumes or average daily flows. The unit-less index has low interannual variability compared to most other indices and correspondingly greater power to detect long-term trends. For example, in their study of 515 Midwestern streams over the 27-year

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*The flow regime of the Portage, draining a row crop agriculture-dominated watershed, reflects surface runoff and subsurface tile flow during storm events. The Au Sable’s watershed is primarily forested, and its streamflow is dominated by ground water inputs with relatively little surface runoff.

†The value of the index will be the same, whichever measure of \( q \) is used.
period from 1975-2001, Baker, et al. found statistically significant increases in flashiness in 22% of the streams (primarily in the eastern portion of the six-state study area) and decreases in 9% of the streams (primarily in the western portion). Although neither Richards nor Baker are hydrologists, the index’s ease of use and the intuitively logical way in which it translates hydrologic stream inputs into hydrologic outputs has led to its wide adoption by many groups including the USGS and many state agencies.

Perhaps his release from the burdens of overseeing the Lab’s operation freed Pete to more fully engage in research for this wasn’t the only significant work he published during this time period. Among other publications, a 2003 paper\textsuperscript{10} found that the Ohio Lake Erie Conservation Reserve Enhancement Program’s (CREP) goal of reducing sediment loads by 6% in 10 years was likely too small to be detectable in three river systems. In the following year he explored the possibility of using long-term water quality datasets on streams in one locality to supplement data on less well-studied streams when establishing and evaluating Total Maximum Daily Load (TMDL) determinations for the more poorly studied streams.\textsuperscript{11}

Ken Krieger’s major publication during this period was a report on a two-year study (April 1988-September 1990) of Old Woman Creek Coastal Wetland as a possible sink and transformer reducing pollutants entering the Central Basin of Lake Erie.\textsuperscript{12} After the Lab’s analysis of 2,150 water samples for an array of nutrients and hydrologic variables, it was found that nutrient concentrations—\textit{in the absence of adequate discharge data}—provided an inadequate basis for determining the wetland’s nutrient removal rates.\textsuperscript{*} Time-weighted mean concentrations (TWMC), for example, greatly overestimated the export of total phosphorus and suspended solids compared to load-based estimates. Annual loads of TSS, NH\textsubscript{3} and TKN increased during passage through the wetland whereas TP, SRP NO\textsubscript{2+3} and soluble reactive silica (SRS) decreased. Interestingly, during storm events various proportions of TP, SRP, NO\textsubscript{2+3} and SRS were removed by the wetland, despite brief hydraulic residence times, while more NH\textsubscript{3} exited the wetland than entered it.

The biology section’s capabilities were enhanced in December 2004 with the part-time hiring of Anne Stearns to work with Krieger on the Lake Erie Comprehensive Survey of macroinvertebrates. Anne’s previous experience had included 8 years working in wastewater treatment and an additional 8 years teaching high school and community college courses. Stearns began full-time employment with the Lab in 2006 where, in addition to working on various macroinvertebrate projects, she also took on quality control duties in the chemistry section, taught Water Pollution Biology and worked on several GIS and modeling projects. Anne left the Water lab in 2008 when her family moved to Manhattan, Kansas.

Also, as Chair of Heidelberg’s Gillmor Hall Development Committee, the amount of time and energy Ken put into the planning, construction and occupying phases of the project—on top of his numerous other responsibilities—would be challenging to even estimate. His obligations in this regard did not end with Gillmor’s official dedication on April 16, 2005. There remained to be addressed all the usual, seemingly innumerable

\textsuperscript{*}Inflow volumes often did not match outflow rates and water entering the wetland was commonly subject to long retention times (a barrier beach at the outlet’s mouth would sometimes block outflow for much of the year).
adjustments that required his involvement with faculty members, the Administration, and various contractors.

Another mid-April 2005 initiation worthy of celebration was the creation of Heidelberg’s online Tributary Loading Website. As the size and quality of the Lab’s nutrient and sediment data sets became more widely known, requests to share that data increased in number and complexity. Responding to these requests was time-consuming as instruction on the appropriate use of the data was crucial to interpretation of any analyses. A $10,000 grant from the Lake Erie Protection Fund allowed the creation of the Ohio Tributary Loading Program Website† consisting of downloadable, continuously updated Excel files of tributary loading data for each river and stream the Lab samples. Over time, the Lab has included in the site numerous summary tools and tutorials for how to access, analyze and interpret the data. The website continues to be heavily used in research and education. A 2009 overview of the HTLP reported:

- For the period April 15, 2005-July 23, 2009, there were 122,461 visits to the site and 34,578 requests for downloads of NCWQR tributary loading data files.

- During the week ending July 23, 2009, there were, on average, 51 downloads per day. Since the site came on line, there had been an average of 22 downloads per day.

- While most of the requests for files came from the .com and .net computer domains, 5.49% (8,196) of the downloads came from .edu (education), 1.41% (2,134) from .gov (U.S. government), 1.27% (1,972) from .ca (Canada) and from 85 other countries.

In the February 10, 2006 issue of the journal Science, the NCWQR’s online database was highlighted in the NETWATCH section of the periodical.

In 1974, amid growing concern about pollution in the Great Lakes, researchers at Heidelberg College in Tiffin, Ohio, began tracking the stream chemistry of the state’s rivers. Their work quantified watershed pollutants from sources such as sewage plants and rural runoff, and it led to efforts to stem the flow of agricultural phosphorus into Lake Erie. At this new site, project leader David Baker, now a professor emeritus, and colleagues share their wealth of data on 11 rivers for scientists to use in courses or research. Visitors can download Excel files for more than 88,000 water samples tested for phosphorus, nitrates, suspended solids, and other components. Tutorials put the information in context, and templates help users analyze the data.

One further development during the Loftus years deserve mention. Through a resolution of the U.S. House of Representatives introduced by Ohio’s Representative Paul E. Gillmor (husband of Heidelberg Board of Trustees member Karen Gillmor), the Water Quality Laboratory’s name was changed in 2004 to the National Center for Water Quality Research (NCWQR). At the time, a fairly large percentage of Heidelberg’s faculty members thought the adjective, “National” was a bit of an ostentatious descriptor for the Lab. Over time, however, as the Lab’s reputation and influence has grown, most have come to find the name as ever more appropriate.

*Dave Baker’s son, Mark, was instrumental in helping the Lab develop the website.
†At this writing, the Tributary Data Download page is located at https://ncwqr.org/monitoring/data/
By early summer 2005, Dave Baker’s cancer had been addressed through his adherence to the treatment regime prescribed by his team of oncologists and the protective and loving care of his wife Peg. There would be future periods of illness and his energy level would never fully match that of his pre-cancer days, but thankfully he felt strong enough to re-assume the Directorship of the Water Lab, on an interim basis, until a national search might find a suitable replacement for Tim Loftus.

Arguably, the NCWQR’s most notable activity during this short period was its hosting of the Sandusky River Watershed Symposium in June 2006. As reviewed in Chapter 2, in May 1975, Heidelberg and Bowling Green co-hosted the Sandusky River Basin Symposium which attracted 150 attendees of which 39 presented 33 papers. Its proceedings were published by the International Joint Commission. The 2006 Symposium was attended by 101 researchers, educators, agriculturalists, environmentalists and others, 29 of whom delivered 26 presentations. In his opening remarks, Dave Baker noted that during the 31 years between the two Symposia, many programs and projects impacting the Sandusky (and other tributaries to Lake Erie) had altered the river’s environmental circumstances including creation of:

- The Ohio Lake Erie phosphorus reduction program
- The Lake Erie Agricultural Systems for Environmental Quality project
- The CRP, CREP and EQIP programs and the Lake Erie Buffer program
- The Sandusky River Watershed Coalition
- The Upper Sandusky TMDL program

It was believed that these programs, along with the removal of the St. John’s Dam and the publication of numerous papers and reports on factors influencing water quality within the river, merited a second overview of the current understanding of the Sandusky River Watershed and a discussion of future research and management challenges ahead. Without referencing the speakers, some of the observations presented at the conference included:

- In the four counties containing most of the Sandusky watershed (Crawford, Seneca, Sandusky, Wyandot) cropland and rural populations had trended downward since 1975 while average farm size and urban populations had trended upward.
- When compared on a unit area basis, TP loads from the Sandusky have been generally higher than the Maumee, Cuyahoga, Grand and Raisin Rivers; SS loads were comparable to the Maumee and Grand but less than the Cuyahoga; DRP was comparable to the Cuyahoga but less than the Maumee; Nitrate loads were the highest of all four rivers though only slightly higher than in the Maumee.
• No significant changes in TP had been observed in the Western, Central or Eastern Basin of Lake Erie since the invasion of Dreissenids (zebra and quagga mussels).

• Within the Sandusky watershed, there are 229 ground and 8 surface water drinking systems.

• There are about 60,000 miles of streams in Ohio of which some 22,500 miles are drainage ditches; only 4,000 of these are under some form of maintenance. Traditional trapezoidal channels are much more subject to bank failure and slumping than 2-stage overwide ditches (with a main channel and small floodplain). Though the latter are more expensive to install and consume usable cropland, in the long term they require less maintenance while enhancing drainage and habitat for wildlife.

• Throughout the watershed, there’s been a great reduction in farmers’ livestock holdings since the 1970s, while the few remaining operations are much larger and more specialized. ODNR’s Manure Nutrient Management (MNM) program and USDA’s Environmental Quality Incentives Program (EQIP) provide technical advice and cost-sharing assistance for farmers seeking to upgrade their manure handling systems.

• Ohio has lost over 90% of its historical wetlands including 300,000 acres of Lake Plain wetlands that had been home to the Great Black Swamp, the draining of which began in 1859. A variety of cost-sharing programs are available for wetland restoration projects.

In the concluding paper of the conference, Pete Richards observed that far more studies on the effectiveness of BMPs have failed to show significant water quality benefits than success. He argued that the source of the problem involves issues of scale. Watershed-wide studies necessarily turn the researcher into an observer, with little control over relevant variables. Replication of “experiments” are rarely feasible; assigning cause-effect relationships between BMP implementation at a given locale and time and water quality at a distant location and time is challenging, especially given variability in weather within the watershed. At the other end of the spectrum, while field- and plot-scale studies allow the researcher a good deal of experimental control, inferring watershed-wide effects on water quality from the results of a highly controlled set of plot studies has its own set of difficulties. Thus, it is not surprising that detecting water quality changes at the watershed scale and demonstrating that these changes are in response to land management practices are difficult exercises. Nonetheless, the long-term accumulation of high quality data at all scales of study, supplemented by land use-water quality modeling, is the path that holds the most promise for providing a solid understanding of these complex relationships.

In June 2006, Heidelberg hired Aaron Roerdink on a one-year contract stipulating that 2/3 of his responsibilities would be with the Lab and the other 1/3 would be teaching in the Chemistry Department.* After receiving his Ph.D. from the University of Wisconsin-Milwaukee, Roerdink worked for several years in the pharmaceutical industry before coming to Heidelberg.

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*In 2012, Administration converted his status to a tenure track position. Although he still holds a dual appointment, as Chair of the Department of Chemistry and Biochemistry his ability to work in the Lab is limited during the academic year.
It was originally thought that he might replace Jack Kramer on his retirement but over time his work in the Lab has evolved more towards quality control.

**Gary Winston, 2007-2010**

Following a national search, Gary Winston was selected in June 2007 to lead the NCWQR as its fourth Director. After receiving his Ph.D. in Biochemistry in 1979 from the University of Nevada-Reno, Gary developed his skills as an environmental toxicologist with post-doctoral study at Washington State University & the Mount Sinai School of Medicine, and thereafter worked his way through academia to become Full Professor and Chair of the Department of Biochemistry at Louisiana State University (1985-1997) and later Head of the Department of Toxicology at North Carolina State University (1997-2001).

From 2001-07, Winston served as Chief Toxicologist in the Israel Ministry of Health where he was involved in the adoption & regulation of the country’s drinking water standards, regulation of industrial waste-water discharge, certification of drinking water treatment chemicals, and risk assessment. His resume listed over 100 peer-reviewed publications in environmental toxicology, several book chapters and a number of technical and risk assessment documents.

Unfortunately, the process by which Winston was selected got his Directorship off to a rocky start. Dave Baker, Ken Krieger and Heidelberg’s President at the time, F. Dominic Dottavio, impressed by Gary’s resume and experience, had him as their preferred candidate for the position. Dave Weininger, then the Vice President for Academic Affairs, remembers that Winston interviewed very well, that he “had all kinds of people skills, high energy and a great sense of humor. He was articulate and bright.” However, Gary’s interactions with the Lab’s technicians during the interviewing process didn’t go well and they strongly petitioned Baker to recommend a different candidate to Dottavio, which Dave did. Nonetheless, the President opted in favor of Winston.

The situation did not improve. In retrospect, Baker’s opinion that “Winston was a mismatch” for the Lab was voiced, in varying degrees of intensity, by all members of the staff who were present at the time. Gary received $20,000 start-up funding to establish his toxicology research, and Jack Kramer built him a gas chromatograph unit to study gas production as a marker of biological process rates. According to staff members, however, Winston would not operate his own equipment, expecting the technicians to conduct his investigations. During his three years with the NCWQR, Gary received one small grant for himself and published one paper, a laboratory study co-authored with undergraduate student Ben Laubender on oxyradical scavenging by Hexagenia mayfly nymphs. Although Ben recalls that he “really enjoyed learning graduate level toxicology from Gary in working on his research,” hopes that Winston’s expertise would attract the financial support to lead the Lab into new areas of water quality study (such as the impact of pharmaceuticals on drinking water and aquatic life) did not materialize.

Watershed modeler Remegio (Rem) Confesor was one of two major hires during Winston’s Directorship. He trained as an agricultural engineer in the Philippines where he conducted research and taught at the Universities of the Philippines at Los Banos (1988-97) and Mindanao (1997-99). Obtaining his Ph.D. from the Department of Agricultural and Biological Engineering at Pennsylvania
State University (2004), he joined the NCWQR in 2008 after completing a four-year Post Doc in the Department of Agricultural Economics at Oregon State University. At Heidelberg, he uses watershed and edge-of-field modeling to explore the effects of agricultural practices and climate change on nutrient and sediment exports from Lake Erie watersheds.

“In fairness to Gary,” Rem has said, “he wanted to steer the Lab into an area of his own expertise, more towards pharmaceutical toxicology. That seemed too much of a shift in orientation for the Lab, especially since he appeared to have little interest in our long-term nutrients and sediment work. Nonetheless, this did represent something of a missed opportunity for us.”

The other Winston era hire, John Crumrine, began his career as a hydrologist for the U.S. Forest Service. In 1978 he took a position as a watershed management technician with the Seneca County Soil and Water District, shifting in the late 1980s to the U.S. Soil Conservation Service† where he remained until retiring in 2003. In 2006, John took a part-time position with the NCWQR as its Agricultural Projects Coordinator that transitioned, in 2007, into full-time employment as the Lab’s environmental extension representative. In that position, John worked with area farmers and agronomists in helping them interpret the Lab’s data and develop research-based Best Management Plans (BMPs) for area farms. In John’s opinion, Gary had done the best he could and that he had tried to add new directions for the Lab without detracting from its existing strengths.

Still, both Rem and John agreed that Winston’s approach did not work well at the NCWQR, given its existing culture and capabilities. VPAA Weininger recalls that Gary “wanted to change everything and did not appear to have a lot of respect for the Lab’s long-term studies.” He also brought up the issue of the numerous financial problems that plagued the Lab during Winston’s Directorship. Heidelberg paid half of Gary’s first year’s salary to allow him to transition to soft money. By his second year, however, his salary had to be covered by the Lab’s general budget. Krieger has noted that for 2010, the year Winston resigned, the Lab was operating almost $91,000 in the red. Baker observed that part of that negative budget was due to Winston’s contract, which stipulated that on parting he was to receive six months’ salary.

In the end, Weininger said, “There was no single event leading to his leaving. He wasn’t fired, he resigned—first from his post in the Lab and then from Heidelberg. It’s not that he wasn’t talented; he clearly was. It just wasn’t a good fit.” Pete Richards, like others commenting on the mismatch between the Lab’s needs and Winston’s expectations, summarized the situation, “He wanted his own research program in areas that were too far removed from the Lab’s primary area of focus,” Krieger added it became apparent that “the type of leadership and grantsmanship skills [the Lab required] proved not to be there. In the end, Gary saw the writing on the wall and opted to leave of his own accord.”‡

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† From the first, Rem’s earnest desire to work for the NCWQR impressed VPAA Weininger who observed that “Foreign nationals require a Green Card to work in the U.S. and our experience had been you could spend $8,000 in attorney’s fees only to lose your hire in a year. Rem, however, took that expense on himself, believing his unique skill set [would fit in especially well with the direction the Lab was heading.]”

‡ Now the Natural Resources Conservation Service.

‡ After leaving Heidelberg, Winston served, prior to retiring, as Adjunct Professor of Toxicology in the Department of Pharmaceutical Sciences at the University of Colorado-Denver School of Medicine and Adjunct Professor of Public Health at UC’s School of Public Health.
A quite different sort of money problem impacting the Lab during the period may have been unavoidable regardless of who was heading up the Lab. The Heidelberg Tributary Loading Program’s (HTLP) long-term monitoring of nutrient and sediment export in a set of tributaries to Lake Erie had long been one of the Water Lab’s premier research programs. Initiated in 1974 with funding provided by the U.S. Corps of Engineers, primary funding for the work shifted to the U.S. EPA in 1980. Six years later funding came under the aegis of the ODNR/USGS co-operative program. Then in 1988, direct State support for the HTLP moved to the ODNR’s Division of Soil and Water Conservation where it remained until 2009.

However, on July 18 of that year, the NCWQR learned that Governor Ted Strickland had issued a line item veto of support for the program in the State’s biennium budget, eliminating its contribution of $250,000 for each of Fiscal Years 2010 and 2011. On August 3, the Lab submitted a Briefing Booklet on the HTLP to the Governor’s Office in hopes of engendering a search by state officials for continued funding of the program. In the short time between those two dates, the Lab received 32 letters in support of the program from representatives of universities, engineering firms and businesses, governmental agencies, citizen groups, international organizations and private citizens, which were included in an appendix to the Booklet. All to no avail; the veto held and for the next two years the Lab’s staff had to scramble to find support to maintain the program.

One of the papers published during this difficult period that drew significant interest (42 citations at this writing) was Richards, et al. 2009 review of sediment and phosphorus loading in the Maumee and Sandusky Rivers over the thirty-year period from 1975-2004. During these three decades, concentrations and loads of suspended solids and particulate phosphate were found to have decreased in both rivers. Because of increased rates of flow during the period, decreases in loads were smaller than decreases in concentrations (6-12% per decade for loads, 10-18% per decade for concentrations). The greatest decreases were observed in summer and fall under low-flow conditions, whereas the smallest decreases were seen in spring under high-flow. Analyses of concentration-flow relationships indicated the changes were not due to weather but reflected increased use of agricultural practices reducing erosion and sediment loss.

Although weather was shown not to have been a factor in the thirty-year pattern of decreases observed in the two river systems, it can nonetheless play a central role in nutrient and sediment export within a given year, as was demonstrated for water year 2007 (October 1, 2006-September 30, 2007) in a 2010 paper by Richards, et al. During that period, the Maumee and Sandusky transported the largest loads of total phosphorus, dissolved reactive phosphorus, total Kjeldahl nitrogen, and chloride observed in in the Lab’s 33 years of monitoring, while loads for particulate phosphorus, nitrate and suspended solids ranked second, fifth and tenth for the Sandusky and forth, eighth and ninth for the Maumee. The study found these abnormal loads were primarily a consequence of total rainfall, which was the largest observed at the Tiffin weather station (for the Sandusky watershed) and nearly the largest at the Toledo station (for the Maumee watershed) during this period.

Based on winter 2008 fertilizer prices from local dealers, replacing the nutrients lost from these watersheds in water year 2007 would cost more than $80,000,000 or $166 per ha ($67 per acre) for every field in the watershed receiving fertilizer in a given year. But while noting that
the weather patterns of 2007 were largely responsible for the magnitude of exported loads, the
researchers also emphasized that the loss of valuable nutrients and sediment could have been
reduced by changes in agricultural practices including subsurface incorporation of fertilizer and
manure rather than surface application, spring fertilization rather than in fall or winter, and the
use of cover crops to reduce erosion and to scavenge nutrients leached from the soil and
decaying crop residues.

Ken Krieger was also actively publishing during the Winston era. As noted in the
previous chapter, his multi-year collaboration with a number of colleagues studying the recovery
of burrowing mayflies in Lake Erie resulted in an important 2007 paper reviewing population
changes in the lake’s three basins during the nine year period from 1997-2005. Working with
Anne Stearns, he also produced a pair of reports for the ODNR on macroinvertebrate
communities as biological indicators of water quality in response to the Department’s
experimental modification of an agricultural drainage ditch and its removal of a low-head
dam. Anne was also lead author, with Ken, of the Atlas of the Aquatic and Semiaquatic True
Bugs, a component of his Old Woman Creek series of illustrated identification guides produced
for the ODNR.

Throughout this time, staff members were continuing the Lab’s active environmental
outreach program, offering dozens of (gratis) presentations to a wide variety of audiences, from
open-house activities for elementary school groups to workshops for professional researchers.
Also, with his well-established working relationships within the local agricultural community,
the full-time employment of John Crumrine significantly enhanced the NCWQR’s ability to
communicate with area farmers and agricultural advisors.

Within Heidelberg, the Lab’s staff collaborated with faculty members and students from
Biology, Chemistry, Geology and Psychology in a student-directed study of alternative paving
options for on-campus parking lots. The year-long project (August 31, 2007 through May 31,
2008) was supported by a $10,000 grant through EPA’s National Student Design Competition
for Sustainability Focusing on People, Prosperity and the Planet. Following a thorough set of
geological, chemical and biological testing of various paving materials and examination of a
variety of parking lot layout and design options, the team proposed that a parking lot near the
Sciences complex under renovation be paved with a porous asphalt, sloped to drain runoff into
vegetated swales along the perimeter, with overflow from large rains directed through buried
drains to a dry retention pond adjacent to the nearby Rock Creek.

Ken Krieger, 2010-2015

Ken Krieger assumed the post of the Lab’s Acting Director upon Gary Winston’s
resignation in April 2010. Three months later, at about the same time Ken was appointed the
NCWQR’s fifth Director, the State of Ohio (as discussed above) withdrew funding for the
Tributary Loading Program for the upcoming two fiscal years. Not an encouraging start to his
term at the helm. If there was an upside to the loss of State funding, it might be that it forced
Ken, Dave and Pete to seek alternative financial support for the program, thereby diversifying
the Lab’s funding base. For Fiscal Years 2010 and 2011, the HTLP was kept afloat with a
collection of large and small grants from the Ohio Lake Erie Protection Fund, the USDA Natural
Resources Conservation Service, the Ohio Water Development Authority, the Great Lakes
Protection Fund, the Environmental Defense Fund, the Michigan Department of Natural Resources, the Andersons Inc., the Northeast Ohio Regional Sewer District, the City of Columbus Division of Sewerage and Drainage and the Miami Conservancy District.

A second possible benefit of the two-year hiatus in State support for the HTLP may have been that it underscored to a wide audience the importance of Heidelberg’s long-term data collection and the equally important value of ensuring its continuation. In any event, all parties heaved a collective sigh of relief in July 2011 when the State restored the HTLP’s funding for the upcoming biennium. At this writing, it accounts for almost one-half the costs of operating the program.

The general consensus of all those interviewed is that Krieger did an excellent job of managing the Lab. Former Heidelberg VPAA Dave Weininger who worked with him through numerous, sometimes difficult issues said, “Ken did an outstanding job.” Pete Richards simply said, “Krieger was a sigh of relief” and Nancy Miller, who had served as Administrative Assistant to all six of the Lab’s Directors added that, “Ken did a wonderful job. He has a gift for detail and didn’t let anything fall through the cracks. He watched every penny.”

Watching every penny was indeed called for, especially during the first two years of his Directorship when Ken had to scrutinize the budget for possible savings and work with Baker to find additional sources of revenue to support the HTLP, without detracting from the Lab’s other important programs or staff salaries. Also, shortly after he assumed the Directorship the Board of Trustees became more interested in the NCWQR’s operation. Several of the Trustees with extensive business experience, recognizing the Lab’s national reputation for scientific excellence and innovation, wanted to explore the possibility of licensing or patenting some of its methods and research products.

Krieger remembers the series of discussions engendered by the Board over the next several years as a productive period of self-review and strategic thinking. In 2012, Ken and Dave submitted, for the Board’s consideration, an Investment Capital Prospectus summarizing the results of that process. The Prospectus included sections reviewing the NCWQR’s historical vision and evolving mission, its long-term database, the perceived market value of that database, an overview of the Lab’s involvement with the University’s academic programs along with plans for future programs, a summary of the Lab’s global research goals and objectives, and a discussion of opportunities for stakeholder capital investment in the Lab’s research. The following excerpt from the Database Market Value section is informative:

The usefulness of our data and studies is related to the fact that we operate at the interface of two major economic activities—agricultural production in northwest Ohio, which annually generates ~$2.5 billion in cash receipts, and the Lake Erie tourism industry, which is estimated to generate ~$10 billion annually. Thus, the economic stakes in reducing the adverse impacts of food production on water resources in Lake Erie are very large in relation to the costs of the key data we provide for the design and assessment of agricultural pollution abatement programs.

Data sets that allow direct assessment of watershed-scale effectiveness and of regional agricultural pollution abatement programs are very scarce. Furthermore, the unparalleled duration and detail of our studies support analyses of the impact of climate change on agricultural runoff.
Because water resource problems associated with food production are global in scope and are likely to be aggravated by the necessity of increasing food production as well as by current directions of climate change, the importance of Heidelberg’s past and ongoing studies is immense.

While the “market value” of our databases is immense, we view those data as being in the public domain. Yet, ongoing investments in the continuation of our programs and approaches represent excellent choices for the many industrial, environmental, foundation and government groups whose missions overlap with ours. We believe that the establishment of a collaborative funding coalition would itself be transformative in freeing our staff from constant grant writing activities that otherwise could be directed to more productive functions.

Here lies the dilemma at the core of the Lab’s perennial problem of financing its wide array of programs. The research “products” it has generated over its many years of study are of enormous value to a wide diversity of users but because of the means by which that research has been funded, they cannot be readily marketed. The Water Lab has operated throughout its existence on “soft money,” the overwhelming majority of which has been acquired through various governmental granting agencies that anticipate the data generated through their support would be made freely available to the wider research community. A common theme voiced in most of the Annual Reports generated by Dave and Ken during their Directorships was the need to establish a consistent basis of financial support for the Lab’s programs. The continual search for grant opportunities, the preparation of grant proposals and the completion and submission of summary reports not only materially diminishes researchers’ time to conduct their studies but places the Lab’s programs on uncertain financial footing. Some form of “collaborative funding coalition,” therefore, has long been a concept the Lab has voiced interest in seeing developed. It still does.

Several staff members have noted that one of the most difficult things for Ken when he became the Lab’s Director was the cutback in his research the position necessarily entailed. For the next several years, much of the laboratory work on his existing projects would be performed by Jakob Boehler. Jake began working on macroinvertebrate projects with Krieger as an undergraduate in 2008. After graduating in 2011, he was employed full-time at the NCWQR. While continuing to work on various of Krieger’s studies, he also began taking on a variety of responsibilities within the Chemistry section—collecting samples, assuming field station maintenance duties on Jack Kramer’s retirement in 2012 and assisting with chemical analyses as needed.

On Ken’s retirement in 2015, Boehler became the Lab’s only staff member with macroinvertebrate identification skills. As his other duties grew, that ability would be called upon less frequently, primarily for occasional contract work for an outside laboratory or in support of various Heidelberg professors’ coursework. Although emphasizing he enjoys his current responsibilities, Jake does miss the biology. Like many other Berg students who have served as research assistants in the Water Lab, it was the possibility of working with Krieger that first drew him to the third floor of Gillmor Hall. Jake comments that, “The biology component of the Lab was the initial attraction for more students than was the chemistry section, even for those who eventually spent most of their time working in the analytical chemistry area. It helped strengthen ties between the Lab and the rest of the University.”
One of the tasks Krieger assigned himself and of which he felt most proud was reintroducing the practice of preparing the Director’s Annual Reports. Dave Baker had prepared seven Reports summarizing the Lab’s principal activities and budgets for fiscal years 1988-89 through 1994-95.* After a hiatus of 16 years, Ken assembled reports for each of his five years as Director, from 2010-2011 to 2014-2015. An extensive overview of his 2012-2013 Annual Report is provided in Appendix A. The review can serve as a representative example of the Lab’s long-term and expanding activities during this period. The majority of the material presented there has been quoted from the Report and not only highlights what Krieger, as Director, felt to be the most important elements of the Laboratory’s activities during the preceding year, but Ken’s writing conveys a clear sense of his enthusiasm for the NCWQR’s work and pride in his staff’s accomplishments.

Ken also established the NCWQR Advisory Council, which first met in May and December 2012 and again in July 2013. The Council was comprised of 18 members representing state and federal agencies, agriculture-related corporations and commodity groups, environmental modeling and engineering firms, watershed conservancy districts, watershed coalition and environmental organizations, environmental research laboratories from other universities, the Seneca County economic development agency and Heidelberg’s Board of Trustees and its Development Office. The Council’s Bylaws stated its purpose was to advise the NCWQR staff with regard to:

- continued overall financial viability and societal relevance of the NCWQR;
- potential sources of funding;
- newly developing or expanding water quality issues of concern to constituencies ranging from local to international levels that might provide new research opportunities for the NCWQR.

While Ken stated in the 2012-2013 Annual Report that the overall objective in establishing the group was “to maintain and enhance the relevance of the NCWQR to the environmental concerns of researchers, managers, policy-makers and the community at large,” he admitted in a 2018 interview that things did not work out quite as he had hoped. “The Council did provide a few helpful ideas about funding and also proved useful as a means for communicating what was going on in the Lab while serving as a forum for members to exchange information [on topics of mutual interest]. However, my expectation the group would offer ideas for new research directions for the Lab never really materialized.”

More of a disappointment was the Lab’s hopes for its work with the consultant group, Public Sector Advisors of Columbus Ohio. Heidelberg entered into a formal agreement with the firm in October 2012 with the expectation its staff would assist the University in obtaining new sources of funding and enhanced statewide and national recognition. The relationship began promisingly with PSA organizing a legislator’s day at the Lab in February 2013 for Ohio and

*Keeping track of the Lab’s annual activities and financial dealings is complicated by how “a year” is defined. For research purposes, the Water Year begins on Oct 1, as does the Federal Budget Year. The Fiscal Year for Ohio, Heidelberg and the Water Lab starts on July 1, while Sea Grant Program support dates from Sep 1. Industrial support is typically keyed to start on Jan 1 as are publications and presentations. Finally, over the years, the start of the University’s Academic Year has varied from one to three weeks before Labor Day.
U.S. Senators, Representative and their aids. Unfortunately, although Heidelberg’s work with the firm did lead to several grants, the annual fee paid for its services proved incommensurate with the value the institution (and the NCWQR) felt it was receiving in return and the connection was terminated a few years later.

Although not referenced in his Annual Report, 2012 was a discouraging year for those involved in Heidelberg’s education program for students interested in water resources. In 1994, after years of discussion and planning, the University initiated its unique Water Resources major which brought WQL staff together with Biology, Chemistry and Geology professors in teaching a curriculum designed to prepare students for careers in research and management of the nation’s water resources. In 2008, the University’s environmental program was restructured to create an overarching Environmental Science major with Biology, Chemistry, Geology and Water Resources tracks. However, in 2012, following an Administration-driven reassessment of campus-wide academic priorities, the four-track major was reduced to a no-track Environmental Science major. In the process, several of the courses that had been distinctive features of the Water Resources track were eliminated including Limnology, a two-semester research requirement and an Environmental Seminar.

Two pivotal events during Krieger’s five years as Director may be said to have shaped the Water Lab’s future for at least the decade following his retirement in 2015: the hiring of Research Scientist Laura T. Johnson in January 2013 and a remarkable event occurring in the early morning hours of Saturday August 2, 2014.

For several days beforehand, concentrations of toxin-secreting cyanobacteria had been building in the vicinity of Toledo’s water intake crib in Lake Erie’s Western Basin. That Saturday, municipal officials were informed the hazardous algal bloom had overwhelmed the city’s ability to treat water being distributed to its citizens and Mayor Michael Collins was forced to inform the area’s 500,000 residents it was no longer safe to use the city’s tap water (Figure 3).

Figure 3. MODIS satellite image of the August 2014 HNAB near Toledo.
Credit: NOAA and NASA.

*The new Water Resources Major supplemented the pre-existing Environmental Biology major.
†In 2019, the University once again revised the Environmental major, creating a new Environmental Science and Sustainability major and an independent Watershed Science Specialization which are discussed in Chapter 5.
They were told to not only avoid drinking the water, but to not use it to brush their teeth, prepare food or to give it to their pets; children and those with weakened immune systems were asked to not even use the water for bathing.

Although the ban was lifted Monday morning, August 4, it was initially unclear how long the problem would persist. The Ohio National Guard brought in 33,000 gallons of drinking water and volunteers handed out bottled water at local high schools. To repeat a relevant observation from *A Primer on Phosphorus* in Chapter 1, this bloom was not a unique occurrence:

…Late-summer HNABs of similar or larger size had plagued the Western Basin for at least a decade preceding the Toledo crisis. The Western Basin concentration of microcystin (the most common cyanotoxin) during the 2011 bloom was 50 times higher than the World Health Organization limit for safe body contact, and 1,200 times higher than the limit for safe drinking water. Also, when dense masses of algae die, fall to the bottom of the lake and are broken down by aerobic (oxygen-consuming) bacteria, hypoxic “dead zones” are created in deeper waters. Lake Erie’s Central Basin has experienced dead zones averaging 4,500 km² since the early 2000s, with the largest event of 8,800 km² occurring in 2012 following the record algal bloom of 2011.

Also as discussed in Chapter 1 and Appendix B, the 2012 amendments to the Great Lakes Water Quality Agreement (GLWQA) between Canada and the U.S. created 13 Articles describing general goals and responsibilities of the two countries and 10 issue-specific Annexes. GLWQA Annex 4: “Nutrients” focused attention directly on phosphorus issues in Lake Erie through a set of Key Commitments. In February 2016 the U.S. and Canada formally adopted three phosphorus loading targets for Lake Erie’s western and central basins (with the finalized U.S. Action Plan for implementing nutrient reductions under Annex 4 released in February 2018) to address those Commitments:

- **To minimize the extent of hypoxic zones in the waters of the central basin of Lake Erie:** a 40 percent reduction in total phosphorus (TP) entering the western and central basins of Lake Erie—from the United States and from Canada—to achieve an annual load of 6,000 metric tons to the central basin. This amounts to a reduction from the United States and Canada of 3,316 metric tons and 212 metric tons respectively [relative to a 2008 baseline].

- **To maintain algal species consistent with healthy aquatic ecosystems in the nearshore waters of the western and central basins of Lake Erie:** a 40 percent reduction in spring TP and soluble reactive phosphorus (SRP) loads from the following watersheds where algae is a localized problem: in Canada, Thames River and Leamington tributaries; and in the United States, Maumee River, River Raisin, Portage River, Toussaint Creek, Sandusky River and Huron River (Ohio).

- **To maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the waters of the western basin of Lake Erie:** a 40 percent reduction in spring TP and SRP loads from the Maumee River in the United States. Using 2008 as the baseline, this equates to a spring (March-July) load of 860 metric tons TP and 186 metric tons SRP.
Data from Heidelberg’s long-term Tributary Loading Program were central to establishing these targets and would clearly play a critical part in evaluating future progress in assessing the Action Plan’s success in achieving its objectives. Furthermore, the Toledo crisis brought the Lake’s phosphorus problems to the public’s attention and with it, the NCWQR. For the foreseeable future, a large component of the Lab’s monitoring, modeling and environmental outreach programs could be viewed as activities addressing, in one way or another, the central organizing theme of helping to solve Lake Erie’s HNAB problem.

As discussed in the next chapter, on becoming the NCWQR’s sixth Director following Krieger’s retirement in December 2015, Laura Johnson would play a major role in orchestrating these activities. Laura received her Ph.D. from Notre Dame in 2008, studying the effect of human land use on stream nutrient processing, and completed a Post Doc working on denitrifying bacterial assemblages in agricultural streams at Indiana University in Bloomington. On joining the NCWQR she got her feet wet working with Baker and Richards on data interpretation, grant writing and making public presentations on the Lab’s work to a variety of audiences.

Five of the several dozen papers published by the Lab’s researchers during this period, will serve here as representative of the diverse studies to which the staff was devoting its energies. One indication of the state of research on water quality issues within the Great Lakes Basin during the 2000s has been the increasing number of NCWQR studies undertaken in collaboration with researchers from other institutions. Indeed, the lead authors of three of the five papers discussed below work in other labs. In large part these collaborations stem from the extraordinary utility of Heidelberg’s long-term and ongoing data collections for addressing a wide array of research problems.

One of the most important collaborations involved researchers from the National Oceanic and Atmospheric Administration (NOAA) and the Great Lakes Environmental Research Laboratory (GLERL). Lead author Richard Stumpf of NOAA’s Center for Coastal Monitoring and Assessment led a team employing satellite remote sensing to quantify the intensity of the cyanobacterial bloom in Lake Erie’s Western Basin for the years from 2002-2011. The researchers found that although the blooms peaked in August or later, the extent of their distribution and intensity correlated with NCWQR data on spring (March-June) total phosphorus (TP) loads and water discharge rates (Q) from the Maumee River. This relationship permitted researchers to develop and publish an annual HNAB forecast prior to the start of the bloom beginning in 2013 (and revised in May 2015 to include data from July):

This week, in response to increased demand for harmful algal bloom information, NOAA researchers and their partners at Heidelberg University began issuing new experimental, early season forecasts of the seasonal harmful algal bloom in western Lake Erie. The information will help resource and public health managers address the toxic blooms, which peak annually in late summer and can affect human and animal health.

The severity of western Lake Erie harmful algal blooms depends on the amount of phosphorus that comes in to the lake from March 1 through July 31, during what is known as the loading season. This early season forecast estimates the bloom severity based on measurements of phosphorus loading from the Maumee River combined with historical records to create the weekly estimates for the remainder of the loading season. They are also compared with NOAA satellite observations.

“By using the environmental data collected by NOAA and our partners, resource managers in the Great Lakes can be better prepared for when harmful algal bloom events happen in their lakeshore communities,” said Holly Bamford, Ph.D., assistant NOAA administrator for NOAA’s National Ocean Service … “As we continue to make advances in ecological forecasting and better understand the severity and timing of blooms, we can help local managers protect their residents and their economies.”

NASA’s National Center for Coastal Ocean Science (NCCOS) website provides Western Basin HNAB forecasts for the upcoming season and assessments of past predictions. It is found at https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-forecasts/.

The NCWQR’s 2014 paper on phosphorus loading to Lake Erie from the Maumee, Sandusky and Cuyahoga Rivers reemphasized Baker’s growing conviction of the overriding importance of bioavailable dissolved reactive phosphate (DRP) in the re-eutrophication of Lake Erie during the period from 1991-2012. Using the Lab’s 1982 and 2007-2010 studies of the bioavailability of both DRP and particulate phosphorus (PP) along with its long-term DRP and total phosphorus (TP) loading data, the study estimated the long-term annual export of bioavailable DRP and bioavailable PP in the three rivers.

Dramatic increases in DRP export occurred in the Maumee and Sandusky Rivers during the period of re-eutrophication, while total particulate phosphorus (TPP) and the bioavailable component of TPP decreased in the Maumee and showed only slight increases in the Sandusky and Cuyahoga. Baker, et al. concluded that increased nonpoint loading of DRP is an important contributing factor to re-eutrophication and that future phosphorus reduction plans for Lake Erie tributaries should involve separate target loads for DRP and TPP (while taking into account the low bioavailability of TPP). Furthermore, since erosion control programs in the Maumee and Sandusky watersheds have been shown to lead to increased DRP export, they also recommended that target loads calling for reduction in TP should be avoided.

The NCWQR’s data was again central to a further study clarifying the role of soluble reactive phosphorus* (SRP) in the re-eutrophication of Lake Erie’s Western and Central Basins. Kane, et al. (2014) found that during the period of 1996-2006, total phytoplankton and seasonal

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*Recall that soluble reactive phosphorus (SRP) is equivalent to dissolved reactive phosphorus (DRP), the term that has been most often used in publications by NCWQR researchers.
cyanobacterial biomasses increased significantly with SRP load from the Maumee River and with the sum of SRP from the Maumee and Sandusky, but not with SRP load from the Sandusky River alone. Neither total phytoplankton nor cyanobacterial biomass, however, was correlated with nitrate load during this period. As in the paper discussed above, the authors concluded that increased SRP loads from the Maumee River were a likely cause of the increased frequency of HNAB’s in Lake Erie and recommended that managers take into consideration both the form and source of nutrients entering the lake in developing their management plans.

Johnson, Richards and Baker collaborated with researchers from the USDA’s Agricultural Research Service and the University of Arkansas in a 2015 paper comparing the transport of phosphorus in surface runoff and tile drainage in Indiana’s St. Joseph River watershed (a sub-watershed within the Maumee watershed). Traditionally, phosphorus has been widely considered to be relatively immobile (especially in comparison with nitrogen compounds) and further, that the great majority of any losses from tiled agricultural fields would occur through surface runoff rather than tile drainage.

However, in this study of four fields that had been closely monitored from 2008-2011, the researchers found that 49% of soluble phosphorus and 48% of total phosphorus losses occurred via tile discharge. Furthermore, peak tile discharge occurred at the same time as peak surface runoff, demonstrating that the development of macropores in the soil allowed infiltrating waters to enter streams directly, bypassing the soil matrix where dissolved nutrients might have been sequestered. The authors concluded that although tile drainage is necessary to produce crops in much of the midwestern United States, it enhances nutrient losses from tiled fields. Therefore, to achieve desired reduction of phosphorus-triggered HNABs in Lake Erie, managers must find ways to reduce nutrient losses from both surface runoff and transport to tile.

In 2013, Ken Krieger co-authored a paper with Bill Zawiski of Ohio EPA’s Division of Surface Water on the possible use of three indices previously developed by the OEPA for tracking changes in fish and macroinvertebrate communities following the removal a dam. Their report—part of a compendium assembled by the Geological Society of America on the challenges of dam removal and river restoration—explored the use of OEPA’s Qualitative Habitat Evaluation Index (QHEI), the Index of Biotic Integrity (IBI, a measure for fish communities) and the Invertebrate Community Index (ICI) in tracking biological changes following the removal of two dams on the Cuyahoga River, one on the Olentangy River and one on the Sandusky River. All three indices were found to reflect rapid changes in habitat and biotic communities following conversion of dam pools to free-flowing water. Post-dam removal scores on the IBI and ICI indices showed that the rivers had met or exceeded scores OEPA expects for designated aquatic life use criteria within one year.

For example, the Sandusky’s St. Johns Dam in rural Seneca County was constructed in 1901 (on the same location as two previous dams dating to around 1837). The 46 m long, 2.2 m high “low head” dam had created an 11.5 km long dam pool. Macroinvertebrates
were sampled at three sites in the dam pool* at the time of its removal in November 2003 and again in the summers of 2004 and 2005. ICI scores for November 2003 ranged from 20-24, none of which met OEPA’s warm-water habitat ICI criterion of 36 for the Eastern Corn Belt Plains Ecoregion. However, in August 2004, just 9 months after dam removal, the mid-pool site registered an ICI score of 34 while the scores for the sites closer to either bank were 44 and 48. In 2005, all three sites had improved scores with the mid-pool site attaining the warm-water criterion and the other two sites meeting the exceptional warm-water criterion (≥ 46).

The following table based on Krieger’s Annual Report for 2013-2014, summarizes the NCWQR’s primary research programs and projects as of fall 2014. It will be noticed that each of the nine projects involved outside collaborators, with five of these headed by Program Directors from other institutions.

<table>
<thead>
<tr>
<th>Research Program</th>
<th>Description</th>
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<tbody>
<tr>
<td>Heidelberg Tributary Loading Program (HTLP)</td>
<td>Begun in 1974, the HTLP has produced the most intensive data set on nutrient and suspended sediment concentrations and export in the U.S., on watershed scales ranging from headwater streams to the Maumee River. For the past three years, NOAA researchers have applied our Maumee phosphorus loading data in predicting summer HABs in Lake Erie.</td>
</tr>
<tr>
<td>Long-Term Agro-Ecosystem Research Program (LTAR)</td>
<td>In 2014, the NCWQR formally joined with two research labs operated by USDA-ARS at the OSU and Purdue. The three groups form the Eastern Corn Belt node of the LTAR network, one of 18 nodes across the U.S. The LTAR Network applies research to solve critical challenges facing agriculture.</td>
</tr>
<tr>
<td>The Comprehensive Private Well Testing Program</td>
<td>Beginning as a nitrate testing program for Ohio in 1987 and expanding to other states in 1990, the program has been conducted in counties of 17 states, including all 88 counties of Ohio.</td>
</tr>
<tr>
<td>A Phosphorus Soil Test Metric for Reducing Dissolved Phosphorus Levels</td>
<td>Beginning in 2007, NCWQR staff worked with its collaborators and a soil-testing laboratory to collect data on the stratification of phosphorus in cropland sols for more than 1,500 fields in the Sandusky River basin. NCWQR also developed a “BMP toolbox” to help farmers reduce runoff of phosphorus from their fields.</td>
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</table>

*Sites were also sampled from above and below the dam pool.
<table>
<thead>
<tr>
<th>Research Program</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Verification and enhancement of NRCS-USDA Nutrient Tracking Tool (NTT) with a Suite of Best Management Practices (BMPs)</strong></td>
<td>The project’s objectives are to 1) demonstrate and quantify the economic and environmental benefits of a suite of BMPs through edge-of-field studies; 2) calibrate and verify the Agricultural Policy Environmental eXtender (APEX) model and the Soil and Water Assessment Tool (SWAT) and examine their BMP effects at different spatial scales in northwest Ohio; 3) calibrate and verify the Nutrient Tracking Tool (NTT) for the Great Lakes Basin; and 4) promote and train producers and stakeholders in the use of NTT to estimate farm yield and nutrient loss.</td>
</tr>
<tr>
<td>Project Director: R. Confesor, NCWQR Collaborators: SRWC, Texas Inst. for Appl. Env. Res., IPM Inst. of N. America, SWCDs, USDA-ARS, local farmer/producers</td>
<td></td>
</tr>
<tr>
<td><strong>Extreme Events Impacts on Water Quality in the Great Lakes: Prediction and Management of Nutrient Loading in a Changing Climate</strong></td>
<td>The NCWQR has been a collaborator on this project since 2010. Its overall goals are to 1) enhance understanding of expected impacts of climate change-induced extreme events on water quality and ecology, with the Great Lakes (and Lake Erie, specifically) as a case study; and 2) develop a framework for integrating human and biogeochemical controls on water quality, ecology and climate that transcends and integrates across social, economic, ecological, hydrological and geosciences perspectives.</td>
</tr>
<tr>
<td>Project Director: A. Michalak, Stanford Univ. Collaborators: LimnoTech, Univ. of Michigan, NOAA GLERL, NCWQR, Grace College</td>
<td></td>
</tr>
<tr>
<td><strong>Evaluating the 4R Nutrient Stewardship Concept and Certification Program in the Western Lake Erie Basin</strong></td>
<td>4R Nutrient Stewardship emphasizes applying fertilizer using the right source at the right rate, time and place. A 4R certification program for nutrient service providers in the WLEB was implemented in March 2014. The goal of this project is to evaluate the impacts of the adoption of 4R Stewardship and of the WLEB Certification program itself on crop productivity and profitability, water quality, and perceptions of growers, nutrient service providers and residents in the WLEB.</td>
</tr>
<tr>
<td><strong>Assessment of Nutrient/Eutrophication Dynamics in Western Lake Erie</strong></td>
<td>Through a combination of in situ experiments, laboratory studies and modeling, this project will improve current understanding of the roles of external and internal nutrient loading, especially as influenced by weather forcing events on the re-occurrence of harmful and nuisance algal blooms (HNABs) in the Western Basin of Lake Erie and of hypoxia in its Central Basin.</td>
</tr>
<tr>
<td>Project Director: G. Hesse, OLEC Collaborators: NCWQR, Univ. of Toledo, Case Western Reserve Univ., Stone Lab-OSU, LimnoTech, USGS-GLSC</td>
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**Research Program**  
*An Online Tributary Loading Tool to Support Harmful Algal Bloom Forecasting in Lake Erie*

- **Project Director:** LimnoTech  
- **Collaborators:** NCWQR, GLOS

**Description**  
The NCWQR, in coordination with LimnoTech and the Great Lakes Observing System (GLOS), is sharing its tributary monitoring data in support of online tools to visualize current trends in nutrient loads (affecting HNABs in Lake Erie) and to make comparisons with previous years. The project’s goals are to 1) expedite water chemistry analyses at the NCWQR, facilitating weekly data updates to a GLOS online database; and 2) develop a set of online tools to visualize trends in nutrient concentrations, flows and loads.

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Top photo: NCWQR staff, 2019. Top row, from the left—Nathan Manning, Tian Guo
Laura Johnson, Barbara Merryfield, Jakob Boehler. Bottom row—Nancy Miller,
Remegio Confessor, Ellen Ewing, Nicole Kuhn (Aaron Roerdink absent)
Middle photos: Ken Krieger, Aaron Roerdink, Pete Richards
Bottom photo: Jack Kramer (), Peggy and David Baker (2010)
Late 1970s-1990s: WQL in the basement of Bareis Hall

Top: Dave Baker probably writing a grant proposal or report, Jack and Ellen in the Lab (c.1978)
Middle: Ellen with a bit of work ahead of her
Bottom: Left-Jack’s six-channel autoanalyzer set-up with chart recorders for measuring dissolved soluble parameters such as nitrites-nitrates and chlorides. Right-Barb Merryfield retrieving a set of water samples from one of the Lab’s automated sampling stations.
Late 2010s: NCWQR on the top floor of Gillmor Hall

Top: One view of the Dave B. Baker Environmental Science Laboratory...with David B. Baker.

Middle: Left-Gas Chromatograph-Mass Spectrometer (GC_MS) used in pesticide assessment
Right-Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) for detecting metals

Bottom: Equipment used for measuring Total Phosphorus (TP) and Total Kjeldahl Nitrogen (TKN)
Solo photos taken during the 2010s

Top: Ellen Ewing, Barb Merryfield
Middle: Pete Richards, Ken Krieger, John Crumrine
Bottom: Rem Confesor, Jake Boehler
Solo photos taken during the 2010s

Top: Aaron Roerdink, Nancy Miller, Laura Johnson
Middle: Tian Guo, Nicole Kuhn, Nate Manning
Bottom: Rem Ellen Ewing and Jake Boehler working with visiting junior high school students
Top:  Field sampling station my Tindall Bridge on the Sandusky River near Fremont, OH.
Middle:  Refrigerated automated sampler unit. Jake conducting a bit of winter maintenance at a field site.
Bottom: Significant storm events in Tiffin—Rock Creek Apr 12, 2013, the Sandusky River Dec 22, 2013
Chapter 5. The NCWQR at Fifty, 2016-2019

Laura Johnson, 2016-

Laura Johnson joined the NCWQR as a Research Scientist in January 2013 after receiving her Ph.D. from Notre Dame (2008) and completing a Post Doc at Indiana University in Bloomington. A quick study, by early June she had already given presentations on the Water Lab’s work before three external groups of professional researchers and a meeting of farmers. Laura’s outgoing personality and fine communication skills would in short order make her a much sought-after speaker on water quality issues, especially after the August 2014 drinking water crisis in Toledo focused the public’s attention on the Lab’s long-term studies on rivers feeding into Lake Erie. The cyanobacteria bloom that put a half-million Toledo-area residents on bottled water for three days had thrown a spotlight on the complex interactions between agriculture and the lake’s water quality, the very topic Heidelberg’s Water Lab had been investigating for almost five decades.

Understanding and managing those interactions has proven a challenging assignment calling for cooperation among a wide array of governmental agencies, independent research facilities, farmers, environmental groups, businesses and industry representatives with diverse and sometimes competing perspectives on the way forward. As discussed in the previous chapter, this has resulted in an increasing proportion of the Water Lab’s work—its monitoring, modeling, data analyses, publications, presentations and environmental outreach programs—being conducted in concert with each of these groups in addressing the central problem of how to best reduce Lake Erie’s annual HNABs to an acceptable level.

On January 1, 2016, following Ken Krieger’s retirement, Johnson became the NCWQR’s sixth Director—seventh, if counting Baker’s two years as interim Director. The first part of this chapter will discuss the Lab’s role, under Laura’s Directorship, within the collaborative network of organizations focusing on Lake Erie’s water quality problems. The second section will explore some of what the future may hold for the Laboratory. As new technologies for collecting and analyzing water samples become available and improved methods for modeling and managing the environmental impacts of agricultural practices come into use, the very nature of what it means to be a “water quality laboratory” is evolving. Also, it is important to keep in mind that a wide array of water resources issues, apart from the re-eutrophication challenges facing Lake Erie, trouble virtually every region of the world. The NCWQR’s experienced staff and technological capabilities have positioned it to extend its leadership in water studies well beyond the Great Lakes onto a global platform, in both research and education.

*See the Primer on Phosphorus section in Chapter 1.
The year 1972 was a pivotal one for Great Lakes water quality issues. In that year, both the Federal Water Pollution Control Act Amendments (more commonly known as the Clean Water Act, CWA) and the Great Lakes Water Quality Agreement (GLWQA) between Canada and the United States were signed. While the CWA (together with significant amendments in 1977, 1987 and 1990) established an EPA-administered regulatory system for enhancing the chemical, physical and biological health of all of the nation's surface waters, the GLWQA focused specifically on the Great Lakes. Following a series of modifications (including important amendments in 1983 and 1987), the agreement was substantially revised in 2012, in large part as a response to the re-eutrophication of Lake Erie.

Of special interest here, the 2012 GLWQA’s “Annex 4: Nutrients” section directed the two nations to develop phosphorus loading targets for Lake Erie and reduction strategies to meet those targets. As discussed in the Primer on Phosphorus section of Chapter 1 and restated in Chapter 4, in February 2016 the U.S. and Canada formally adopted three phosphorus loading targets for Lake Erie’s Western and Central Basins1 (with the finalized U.S. Action Plan for implementing nutrient reductions under Annex 4 released in February 2018). In brief, the Agreement committed the two countries:

*To minimize the extent of hypoxic zones in the waters of the central basin of Lake Erie*: a target of 6,000 MT of TP, which equates to a 40 percent reduction in TP entering the western and central basins of Lake Erie from the United States and Canada [relative to a 2008 baseline].

*To maintain algal species consistent with healthy aquatic ecosystems in the nearshore waters of the western and central basins of Lake Erie*: a 40 percent reduction in spring TP and DRP loads from watersheds where algae is a localized problem.

*To maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the waters of the western basin of Lake Erie*: a target of 860 MT TP and 186 MT DRP, which is a 40 percent reduction in spring TP and DRP loads compared to 2008 from the Maumee River in the United States, to be met 9 out of 10 years.

In 2019, Johnson contributed to a paper commenting on the challenges to achieving these phosphorus targets for Lake Erie.2 The article’s lead author was Ohio State’s Robyn Wilson and, in addition to Laura, it included eight other prominent water quality researchers from various institutions around the State. This level of collaboration has become increasingly common in research seeking to understand the complex interplay between land management practices and water quality. With various research groups focusing on different aspects of the story, no one program has command of all the relevant information; sharing data and insights has become the norm. The Wilson paper highlighted some of the knotty issues facing scientists and managers attempting to address Lake Erie’s HNAB issues via the GLWQA Annex 4 phosphorus objectives:

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1 Appendix B presents a detailed history of the GLWQA since its inception in 1972.
• From the mid-1990s through the 2010s, particulate phosphorus (PP) inputs into the lake declined slightly while dissolved reactive phosphorus (DRP) loading increased 132%. Although the targets address both PP and DRP, the authors note that strategies for reducing HNABs should specifically focus on total bioavailable phosphorus (TBAP*), the forms that are readily metabolized by algae and cyanobacteria. While virtually 100% of DRP is bioavailable, that number drops to about 24-26% for PP.

• 88-93% of phosphorus loads entering the Lake from the Maumee and Sandusky Rivers comes from nonpoint sources. Over 70% of the area in these watersheds are agricultural lands.

• From 2002-2013, 70-90% of phosphorus and nitrogen loads from the Maumee River occurred in just 20% of flows as a result of nutrient pulses during and following storm events.

• From the 1970s to the mid-1980s, phosphorus fertilizer was applied in the Maumee watershed at a rate that was 4.4-17.4 lbs/acre above crop-removal rates, resulting in significant accumulation of phosphorus in the soil. Since the mid-1990s, application rates are reported to be near crop-removal rates (of about 10-40 lbs/acre of P2O5). However, while 52% of fields within the watershed currently experience phosphorus applications at levels below removal rates, 42% of fields account for 78% of TP runoff and 80% of sediments.

• Highly phosphorus-stratified† soils are found most commonly in fields managed with no-till cultivation and broadcast fertilizer application.

• As of a 2018 survey within the Maumee watershed, 94% of farmers within the Western Lake Erie Basin (WLEB) report a willingness to determine fertilizer application rates based on regular soil testing. Similar rates were also reported for farmer willingness to avoid winter fertilizer application‡ and to delay application prior to significant rainfall. Additionally, some 75% of farmers reported willingness to use subsurface placement of fertilizers (instead of surface broadcasting) in the future and 55% said they were willing to use cover crops, though not without financial incentives to offset short-term costs and risks.

• Modeling results suggest that although there are multiple pathways to achieving the targeted 40% reductions in phosphorus loading to Lake Erie, all typically require 50-75% farmer adoption of best management practices (BMPs) such as the use of subsurface fertilizer placement and the planting of winter cover crops. But current adoption rates of such practices range only 20-50% across the WLEB, with relatively little change having been observed between 2015 and 2017 (29 and 35%, respectively).

• Survey results indicate the biggest barrier to increased rates of BMP adoption by farmers isn’t their lack of concern or knowledge about the impact of nutrients on water quality, but misgivings that the proposed BMPs are feasible to implement and likely to be effective.

*Total bioavailable phosphorus, abbreviated as TBAP or TBP, is discussed at length at the end of this section.
†Highest concentration of phosphorus in the top layer of soil. Stratification of phosphorus is also discussed below.
‡Winter application of fertilizer is now regulated in Ohio.
In a 2017 evaluation of five mathematical models addressing phosphorus load reduction strategies for the Maumee River (to which NCWQR’s Rem Confesor contributed), Scavia et al.\(^3\) reported that:

Any successful pathway [leading to the GLWQA’s 40% phosphorus reduction targets] will require large scale implementation of multiple practices. Achieving such implementation will require local, state/provincial and federal agency collaboration with the private sector to set implementation goals and [will] demand innovation and honest assessments of water quality-related programs, policies and partnerships.

So the challenges are many and varied. One of the essential tasks for which the NCWQR is uniquely well-suited entails the monitoring of nutrient concentrations in tributaries feeding into Lake Erie through its long-standing Heidelberg Tributary Loading Program (HTLP). But that data has also served at least two other important functions: supplying the empirical data for developing and testing mathematical models exploring the potential impact of various land management practices and climate change on water quality; and, since 2012, providing resource managers and the public with spring forecasts for late-summer HNABs in the Western Basin of Lake Erie.

As discussed in Chapter 4, beginning in 2012, the NCWQR entered into a collaborative arrangement with the National Oceanic and Atmospheric Administration (NOAA) and the Great Lakes Environmental Research Laboratory (GLERL) to develop predictions of the distribution and intensity of late-summer HNABs based on Heidelberg’s data on spring (March-June) TP loads and water discharge rates (i.e., rates of flow, \(Q\)) from the Maumee River.\(^4\) In 2016, the procedure was updated.\(^5\) The original model had been based on ten years of HTLP data for the Maumee River and satellite imagery of HNABs in Lake Erie from 2001-2011. However, 2011, 2013, 2014 and 2015 were found to be exceptional years, with 2015’s bloom deemed the most extensive ever seen in the lake, covering over 5,000 km\(^2\) and impacting both U.S. and Canadian shores.

Adding in data since 2011, it was found that the best estimates of late-summer bloom biomass were based on discharge (\(Q\)) or total bioavailable phosphorus (TBAP) from March through July,\(^*\) (In years where June lake temperatures were too cool for *Microcystis* growth—less than 17\(^9\)C—July loads are excluded.\(^‡\)) The authors noted that while discharge from the Maumee provided the least uncertainty in estimates, TBAP provided better information on phosphorus loads for managers developing bloom reduction strategies.\(^‡\) HNAB prediction, however, is an evolving science, as the 2018 bloom in the Western Basin amply demonstrated.

NOAA’s National Centers for Coastal Ocean Science (NCCOS) uses a suite of different models to predict the extent and severity of the late-summer HNAB in the Western Basin (an “ensemble forecasting” approach). Each model uses the same raw information (discharge rates, phosphorus concentrations, etc.) to calculate a Severity Index (SI) for the upcoming bloom season, where SI = predicted bloom intensity \(x\) predicted bloom extent (\(\mu g/L \times \text{km}^2\)) over the peak 30 days.

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\(^*\)Rather than March through June as in the original model.
\(^‡\)Cyanobacteria tend to favor temperatures >20\(^9\)C.
\(^‡\)Since typical DRP concentrations within the Western Basin are <0.02 mg/L, a reduction in TBP loading would be expected to reduce the area of the lake with phosphorus concentrations favoring cyanobacteria growth, regardless of the rate at which water is discharged from the Maumee River.
of a bloom. Encouragingly, all predictions, with the exception of 2015, from 2012-2017 had been virtually spot on. However, as is illustrated in Figures 1 and 2 (taken from the NCCOS 2018 Seasonal Assessment web page)\(^6\), all models overestimated the actual severity of the 2018 bloom. The median ensemble SI of 6.0 (the individual models’ estimates ranged from 4.9-7.8) was much higher than the observed SI of 3.6.

![Figure 1. Bloom severity indices for 2002-2018, and the forecast for 2018.](image1)

![Figure 2. TBAP from the Maumee River for 2018 compared to other selected years.](image2)

(Both Figures from Laura Johnson, personal communication)

As of this writing, the NCCOS website has indicated the reasons for the overestimates were under review, but it has noted that the 2018 bloom had been unusual in that it started early (the last week of June), probably as a result of the early warming of the lake starting at the end of May. Also, the bloom never recovered from a storm on September 9-10 that resulted in one of the earliest ends to the bloom season (first week of October) that has been seen in recent times.

In discussing the striking difference between observed SI and TBAP values for 2018 and 2017 (Figures 1 and 2), it was noted that although river discharge and rainfall in the Maumee watershed for 2018 were typical of long-term averages, they were higher in March and April, lower in May and June, and very low in July. This is much different from 2017, which experienced extremely wet months in May and July, leading to very high discharge and TBAP loads in those months.

**On the importance of mathematical modeling in the Lab’s arsenal of analytical tools**

Rem Confesor views modeling as a continuous process involving feedback between scientists’ evolving understanding of a complex problem and the testing of a model’s predictions against observed data. When a model is deemed “bad” is it because of the underlying science, uncertainty of available data, or incorrect assumptions? Rem argues that rather than rejecting a poorly performing model out of hand, it is more useful to ask why it has performed badly.
It’s an opportunity to advance your knowledge of the problem you are trying to address; you discover the difficulty with the model and it gives you a leg up in understanding which factors are of the greatest importance.

Modeling is the only tool we have with the ability to integrate economics, hydrology, land management, climate change and other factors in advancing our understanding of the agriculture-water quality interface and for making scientifically-sound recommendations for improved land management practices. It will be the technology by which future decisions will be made and it has already become a central component of the Water Lab’s research efforts.

Field-scale models [as opposed to whole-watershed models] that are currently available are strong enough to provide reasonable options for a given farmer’s operation. But how do you convince farmers to adopt model-based recommendations? Maps and data are useful but only insofar as they are believed. Farmers generally trust their local Soil and Water Conservation advisers and we are working to develop strong collaborative relationships with them.

An effective model is one that improves understanding of a system under study and has predictive power for how that system would be expected to operate under a given set of relevant conditions. As (a.) better empirical data on those “relevant conditions” become available, and (b.) researchers’ understanding of how those conditions influence the behavior of the system becomes more nuanced, it can be expected that the models they develop will become more accurate and, therefore, of greater use to resource managers and policy makers.

The following two sections offer an examination of how the Lab’s long-term collection of empirical data on water quality within the WLEB are informing its increasing emphasis on the development of mathematical models for understanding the dominant factors determining water quality within the region. As of 2019, NCWQR researchers generally address modeling projects in one of two teams, with Rem Confesor (2008), Tian Guo (2017) and undergraduate Environmental Science and Mathematics double major Judy Smith working on an array of projects including edge-of-field and climate change impacts on water quality, and Laura Johnson and Nate Manning (2018) who, among other projects, have included modeling of instream metabolic processes in their work. We will begin by considering one project from each team and conclude with an examination of set of collaborative studies addressing the pivotal question, what have we learned about those aspects of current agricultural practices in the WLEB that are of primary importance as drivers of unacceptable HNABs in Lake Erie?

a.) Modeling the effects of climate change on Lake Erie HNABs. Rem Confesor was invited by a Swedish colleague to participate in a 2017 workshop sponsored by the European Centre for Medium-Range Weather Forecasts (ECMWF), which uses imagery from the Copernicus satellite in support of the Copernicus Climate Change Service (C3S). The goal of the Service is to provide reliable information about current and past climatic conditions along with projections based on various scenarios of climate change contributors in the future. C3S predictions are based on highly sophisticated supercomputer-based Global Circulation Models (GCMs) that use masses of empirical data to simulate the planet’s future atmospheric and oceanic conditions under different environmental situations. The ECMWF employs an ensemble approach to creating C3S predictions by averaging the predictions from all available GCMs.
Through Confesor, Heidelberg was invited to serve as one of a small set of “Global Case Users” selected from six continents to develop test studies exploring how C3S predictions might be used in their region. Rem chose to work with raw data supplied by 19 different GCMs for the Maumee and Old Woman Creek watersheds* for the period 1983-2100. Raw Copernicus satellite imagery covers 2-degree blocks of about 220 km² but is generally processed by a regression model to 0.5-degree blocks of about 50 km² for use in GCMs. Working with Tian Guo and Judy Smith, Rem’s team further processed the 50 x 50 km data down to 20 x 20 km blocks which were then used to generate 19 different sets of C3S climate predictions.

But Rem went a good deal further than was requested for the ECMWF study. He then entered the climate predictions, along with information on nutrient loadings from the Lab’s HTLP data, into USDA’s SWAT model† to predict flow, nitrogen, phosphorus and sediment loadings for the Maumee and Old Woman Creek for the years 2041-2060. The results of those predictions he then used in the 2016 model of Stumpf, et al (discussed above) for forecasting annual cyanobacterial blooms in Lake Erie. He ran each of the (19) HNAB analyses two ways: with the assumption that farmers do not adopt the recommended BMPs currently being advocated as the most promising mechanism to reduce Lake Erie HNABs, and the with the assumption that they do adopt the BMPs.

The results were disheartening. The ensemble of models all suggested that without adoption managers could expect about a doubling of the frequency of severe HNABs by mid-century. But even with widespread adoption of the recommended BMPs, the models predicted, at best, a status quo situation without much improvement by mid-century. In March 2019, Rem gave a report on this work to the Global Case Users Subcommittee at an ECWMF meeting in Portugal. The organizers of the program were so impressed by the study that they asked him to give a Plenary talk on the project before the entire assembly.

b.) Modeling the linkage between nutrient loads and GPP in streams. At several points in this history, reference has been made to 4R Nutrient Stewardship. The Fertilizer Institute defines the four Rs of sound fertilizer management as using the Right Source of fertilizer (matching fertilizer type to crop needs), at the Right Rate (given crop needs), at the Right Time (when needed) in the Right Place (applying them where crops can best make use of them). Though usefully stated in this concise way, correctly applying the 4R principals to a given field can be challenging as the specific Rs will depend on characteristics such as soil type, cropping system, management techniques and climate.

In March 2014, the 4R Advisory Committee, a consortium of stakeholders from business, government, university, and non-governmental sectors with the common goal of maintaining agricultural productivity while also improving the water quality of Lake Erie and its contributing watersheds, launched the 4R Nutrient Stewardship Certification Program to encourage agricultural retailers, nutrient service providers and other certified professionals to adopt

*Recall that that the Maumee and Old Woman Creek watersheds feed into Lake Erie’s Western and Central Basins.
†USDA’s Soil and Water Assessment Tool (SWAT) is a widely applied hydrological model used to quantify the impact of agricultural practices on the physical and chemical characteristics of rivers in complex watersheds.
scientifically developed best management practices through the 4Rs. The voluntary program provides recognized standards for agricultural retailers and nutrient service providers* in the Western Lake Erie Basin (Indiana, Michigan and Ohio)† and represents a major effort by the industry to promote 4R stewardship among its client farmers within the watershed. As of 2017, nearly 2 million acres within the WLEB were being managed by one of 37 4R Certified retailer/service providers.‡

In 2013, the Foundation for Agronomic Research (now managed by the International Plant Nutrition Institute, IPNI) began accepting grant applications to the newly created 4R Research Fund, which had been established to support research on the social, economic and environmental impacts of 4R stewardship. As part of a team evaluating the 4R stewardship concept and certification program in the Western Lake Erie Basin (headed by Kevin King of USDA’s Agricultural Research Station in Columbus), Laura Johnson took on a project attempting to assess the impact of 4R stewardship on the instream biota of area creeks and rivers.

To actually monitor the potential effects on the fauna and flora in water bodies receiving inputs from fields under 4R management regimes would be a Herculean task and one very unlikely to reveal anything approaching a cause-and-effect relationship; there are just too many other factors influencing population distribution and abundance. Rather, Johnson reasoned that measures of Gross Primary Productivity (GPP) within a stream could prove a reasonable indicator of the overall biotic activity with the water body.

In both terrestrial and aquatic ecosystems, “gross primary productivity” generally refers to either the total amount of organic matter (biomass) or energy that is synthesized from sunlight and atmospheric or aqueous carbon dioxide by photosynthetic plants, algae and cyanobacteria.‡ (Net primary productivity, NPP, is GPP minus lost energy or biomass production due to producers’ need to devote a portion of their resources to self-maintenance.) Ecologists have long used GPP (and NPP) as a handy indicator of the productivity of all members of an ecosystem since animals can only produce their own organic matter by consuming primary producers like plants. In general, ecosystems with little primary production per year cannot have as large populations of animals as those with higher annual productivity—up to a point. Excessive (typically nutrient-driven) production can result in hyper-eutrophic conditions with resultant HNABs negatively impacting aquatic animals.

Since oxygen is produced as a byproduct of photosynthesis, and all living organisms deplete oxygen in their daily metabolic processes, various methods for measuring GPP and NPP in aquatic systems have been developed based on monitoring dissolved oxygen (DO) using sensors deployed in situ. The thinking underlying Johnson’s 4R study was that if widespread adoption of 4R stewardship in the WLEB were to have a positive effect on the biota of area streams and rivers, it would most likely be a function of reduced nutrients and sediment entering

*The 3-year certification program is open to agricultural retailers, service providers, and certified crop advisers, not individual farmers.
†In 2017, the 4R Nutrient Stewardship Certification Program was launched to the full state of Ohio, offering all Ohio-based agricultural retailers and nutrient service providers the opportunity to participate in efforts to improve the quality of Ohio’s waterways.
‡Chemosynthetic generation of organic matter and energy is also important in many systems.
receiving waters, which would in turn impact measured levels of GPP. The first step of a study of this relationship was to establish a baseline of past and current conditions for a sample set of watersheds. Because of the NCWQR’s long-term HTLP, the Lab had a surfeit of appropriate data to do this—multiple streams and rivers with four years of nutrient, sediment and DO measurements taken every 15 minutes.

The problem was how to calculate ecosystem GPP and respiration* rates from this mass of data? Nate Manning was in part hired to identify or build the appropriate metabolism models to work through that assignment and apply them to the existing dataset. As of this writing, he has completed that task using the USGS Metabolizer R model and is in the process of trying to make sense of patterns revealed by his modified model for six test streams.

**Building a case for reconsideration of the 2016 GLWQA phosphorus targets**

Consider the following set of six publications co-authored by NCWQR researchers. Each one addresses some consequence of scientists’ evolving understanding of how the shift from conventional tillage to conservation tillage has impacted the hydrogeology of soils underlying farmed fields and, subsequently, of off-site hydrology. These seemingly esoteric increases in knowledge have together led to improved insights into the dominant factors governing the transport of nutrients from agricultural lands into tributaries of Lake Erie and, as is discussed in the final paper of the set, ultimately to a recommendation that the 2016 GLWQA targeted phosphorus objectives would benefit from reconsideration.

First a bit of review. As noted in Chapter 3, a four-year study by Ken Krieger of over 2,000 fields in the Rock and Honey Creek watersheds (1982-1985) revealed low adoption rates of conservation tillage (i.e., reduced or no-till) methods—just 14% for soybeans and 0-6% for corn.8 A decade later, however, conservation tillage rates had jumped to 51% of corn and soybean acreage in Northwest Ohio.9 The USDA’s Natural Resource Conservation Service reported in 201110 that no-till management was currently used within the WLEB on about 65% of soybeans, 71% of the wheat and 19% of the corn, with mulch tillage (a form of conservation tillage that mixes crop residue with the soil while leaving some amount of residue on the surface) accounting for 9, 19 and 12% of those crops. The reduced compaction of fields with heavy (and expensive to operate) machinery and consequent improvements in soil health, marked reduction in soil loss due to erosion, and other advantages of conservation tillage are well known. More recently, however, the creation of macropores and increased stratification of phosphorus within the top several inches of soils under reduced tillage management have been seen as more problematic.

The clayey soils throughout Northwest Ohio typically require subsurface drainage systems (tiling) to remove excess water from agricultural fields. It has been discovered that the movement of DRP through macropores (fissures leading down from the soil’s surface that commonly develop in fields being managed under conservation tillage) into subsurface

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*Respiration generally refers to “cellular respiration,” the metabolic process by which organisms use oxygen in making use of energy to support their bodily functions.*
tiles represents a significant pathway for phosphorus loading into area streams and rivers. A 2016 paper co-authored by Confesor developed an improved model of tracking nutrient losses from agricultural fields by accounting for such macropore flow. USDA’s APEX* 0806 model has been widely used to estimate nutrient losses from tiled landscapes, but with limited success when predicting edge-of-field DRP loadings. The team modified APEX’s DRP model so as to integrate macropore flow (creating APEX-macro) which was then tested in a 31-month study of a 9,2 ha tiled field site within the Grand Lake Saint Marys watershed.

Empirical data from the field study showed that, on average, macropore flow about equaled diffuse flow (i.e., through inter-soil particle spaces) as a pathway for water from surface to subsurface tiles. Incorporating macropore flow into the model, APEX-macro provided significant improvement in edge-of-field modeling of DRP discharge. It is worth noting that APEX is the main driver of the Nutrient Tracking Tool (NTT) developed at the University of Texas, Tarleton, which Rem has calibrated and modified for use in WLEB watershed.

The development, testing and evaluation of HTLP data commonly involves the efforts of a team of researchers from a variety of institutions who bring different datasets, skills and perspectives to the table. For example, a 2016 paper that examined factors controlling phosphorus loading in tributaries to Lake Erie† was co-authored by Mark Williams of USDA’s National Soil Erosion Research Lab in West Lafayette IN, Kevin King and Norman Fausey of USDA’s Agricultural Research Service (ARS), Soil Erosion Research Lab in Columbus OH, David Baker and Laura Johnson of the NCWQR in Tiffin OH, and Douglas Smith of USDA’s ARS, Grassland, Soil and Water Research Lab in Temple TX. The study used several trend analysis tools‡ to determine whether hydrologic or biogeochemical processes were the dominant factors in observed variation in DRP load, TP load and suspended solids in a 40-year dataset (1974-2014) for the Maumee and Sandusky Rivers.

As expected (based on the researchers’ long experience), hydrologic processes were primarily responsible for loading patterns; phosphorus and sediment export was strongly correlated with discharge (rates of flow). The study also found that

The nature and behavior of observed phosphorus transport [from fields to rivers] likely stems from a large ubiquitous source of phosphorus present within the watersheds. … The results suggest that changes in both precipitation patterns (i.e., variability in precipitation) and watershed hydrologic response (i.e., water residence time) are likely explanations for observed increases in water and phosphorus loading in the Maumee and Sandusky watersheds.

Following this, a 2017 paper by lead author Helen Jarvie§ assessed the rate of increase in cumulative daily loads over the period of record for the Maumee, Sandusky, and Raisin rivers. She noted two change points- one in 1984 when daily DRP loading rate decreased and another in 2002 when daily DRP loading increased. She then attributed 65% of the increase in DRP loads after 2002 to increased DRP delivery and only 35% to increased

*APEX = Agricultural Policy Environmental eXtender model.
†Lorenz Inequality and Degree of Memory analyses, which quantify patterns in time-series data such as for the 40-year dataset used in this study.
runoff volumes. In assessing the changes in the landscape since 2002, her analysis suggests the increase in conservation practices to reduce erosion have had unintended impacts contributing to the increased DRP loads that reached a critical threshold around 2002.

Taken together, the analyses point to (a.) the heavy buildup of phosphorus in the upper layers of farmed fields (primarily due to many years of excessive fertilizer applications via surface broadcasting and to enhanced vertical stratification of phosphorus under conservation tillage) and (b.) climatic changes (increased precipitation and increased flashiness of discharge), working in tandem as the primary drivers of the increased DRP concentrations and loadings observed in the two rivers since the mid-1990s.

NCWQR scientists collaborated on an important paper in 2017 that addressed the development of vertical stratification of phosphorus in agricultural fields under conservation tillage.\(^\text{14}\) The buildup of phosphorus in the top soil layer of such fields is caused by the release of nutrients during the breakdown of surficial crop residues, together with years of broadcast (surface) applications of fertilizers and manure coupled with the lack of inversion tillage. The Water Lab enlisted the help of local Certified Crop Advisers (CCAs) for a five-year stratification study within the Sandusky River watershed. CCAs typically base their recommendations to farmers for application rates of phosphorus fertilizer for a given field on a set of Soil Test Phosphorus (STP) measurements—analyses of bioavailable phosphorus\(^*\) in the top 20 cm of soil—obtained from various locations in the field.

For this project, in addition to the routine set of 20 cm soil cores they collected from a given field, the CCAs also collected a second set of cores for the stratification study. Each study core was subsequently divided into a series of sections for STP determination by an independent soil lab. The most significant finding of the study (of over 1,500 fields examined) was that mean STP levels measured for the upper 2.5 cm of soil proved to be 55% higher than mean STP values based on entire 0-20 cm cores.

Because the concentration of DRP in runoff from agricultural fields had been shown to be proportional to DRP concentration in the topmost layer of soil, the authors recommended that two types of STP measures are needed for agricultural landscapes: agronomic-STP (A-STP) based on the traditional 0-20 cm cores for use in supporting fertilizer management, and environmental-STP (E-STP) reflecting conditions in the topmost layer of soil. They concluded with a suggestion (that has proved to be controversial for some strong advocates of cover crops) that “reducing stratification by a one-time soil inversion has the potential for larger and quicker reductions in DRP runoff risk than practices related to drawing down A-STP levels.”

At this point, an interesting problem presents itself. Numerous studies have demonstrated that increased precipitation and stream flashiness on the one hand and DRP loadings in WLEB tributaries on the other have both seen substantial increases since at least the mid-1990s. How then are researchers

\(^*\text{Most of the phosphorus in soils (typically >95%) is “stable soil phosphorus” that is tightly bound to minerals or in organic forms that are not readily available for use by plants. Mehlich-3 and Bray Kurtz P1 (Bray P1), the two most commonly used STP indices in the Great Lakes region, measure relatively bioavailable “solution and labile (less tightly bound than stable) soil phosphorus,” which together generally account for 1-5% of the phosphorus in soils. The higher the STP value obtained for a given field, the greater the potential for DRP and PP runoff.}\)
and policy makers to discern the extent to which land management practices influence DRP levels within these tributaries—above and beyond the influence of hydrologic changes? The problem is made more challenging by the fact that from year-to-year there can be a great deal of variability in precipitation and streamflow, which can obscure researchers’ ability to identify the existence of long-term trends. Johnson and Confesor contributed to a 2019 paper addressing the issue.

In 2010, USGS researchers published a model for analyzing long-term water quality data sets, referred to by the ungainly name of the Weighted Regressions on Time, Discharge and Season (WRTDS) model. The authors of the 2019 paper modified the WRTDS model by including information on long-term changes in annual variability in streamflow. This extended-WRTDS model was then applied to a study of DRP trends observed in five streams within the WLEB that had continuous nutrient and discharge monitoring records from 1995-2015. Over this 20-year period, DRP loads had increased in the five streams from 109-322%. The extended-WRTDS model was able to attribute one-third of that increase to increasing discharge and the remaining two-thirds to increased concentrations for any given discharge in recent years.

Figure 3 illustrates this finding with a chart depicting model-derived expected relationships between DRP concentrations and stream flow in Honey Creek for two dates:

Figure 3. Example of estimated concentration-discharge relationship for two dates: August 1, 1995 and August 1, 2013, for dissolved reactive phosphorus (DRP) in Honey Creek at Melmore, OH. (Choquette, et al., 2019)

August 1 of 1995 and 2013. To create the two curves, the model first summarized data sets consisting of hundreds of thousands of water quality samples and discharge rates for Honey Creek over the entire 20-year period of the study and then produced expected concentration-to-discharge relationship curves for each day—after having accounted for short-term (year-to-year) fluctuations in discharge. Thus, the curves do not present observed concentrations and flows for these two dates but expected concentrations for any discharge rate (that could theoretically have been seen on that day), as calculated by the extended-WRTDS model. Examining the figure shows that the model predicted a relatively small increase of about 30% in expected DRP

*The model’s title at least has the advantage of summarizing, for those with statistical skills, what it basically does.
concentrations between 1995 and 2013 at the low discharge rate of 0.05 m³/s. However, at the high discharge rate of 10 m³/s, DRP concentrations would have been expected to have doubled between the two years.

This example demonstrates that for both years, DRP concentrations would be expected to increase as streamflow increases, but also that for any given rate of streamflow, DRP concentrations would be expected to be greater in 2013 than in 1995 and this difference would be amplified at higher discharge rates. In concluding the paper, the authors emphasized that to avoid making misleading conclusions about long-term changes in water quality, it is critical that researchers not be overly influenced by short-term (year-to-year) variability in nutrient loads and concentrations that are due to essentially random sequences of wet and dry periods.

It has long been known that nutrient trends in the Great Lakes region reflect, in some way, climatic changes and increases in streamflow, changing agricultural management practices, and changes in precipitation-runoff due to modifications in land-use practices and artificial drainage. Modeling based on the NCWQR’s long-term HTLP data provides a mechanism for determining the relative importance of each of these factors.

In the early 1970s when Dave Baker and Jack Kramer were first designing their procedures for collecting, analyzing and interpreting water quality samples from the Sandusky River, it was enough of a task to get out the word that storm events have a significant impact on riverine nutrient concentrations. But as the Lab’s programs have matured and its reputation as a leading source of reliable information on water quality in tributaries supplying Lake Erie has spread, the expectation that NCWQR research might also inform policy and management decisions has added a new dimension to the Lab’s environmental extension mission.

Laura Johnson tells the story of a paper she coauthored in 2018 that addressed water quality changes in a major tributary to Grand Lake Saint Marys (GLSM, Figure 4), Ohio since the State declared it a distressed watershed in 2011.17 At 52 km², GLSM in Mercer and Auglaize

Figure 4. Subwatershed map of Chickasaw Creek with surrounding Grand Lake St. Marys watershed. The star indicates the location of the NCWQR’s long-term water quality monitoring station. (Jacquemin, et al. 2018.)
Counties in Northwest Ohio is the state’s largest reservoir. In 2009, the US EPA identified its watershed as belonging to the 99th nationwide percentile for total microcystins. The Ohio EPA has issued consistent “no contact” warnings for the lake’s hypereutrophic waters and in 2011 it attached a “distressed watershed” label to the GLSM system.

The 2018 study focused on Chickasaw Creek, a major tributary to GLSM draining some 25% of the lake’s total 241 km² watershed. Its watershed is dominated (80-90%) by row crop and livestock operations. Figure 4 presents a typical aerial photo of GLSM during a late-summer HNAB with the Chickasaw watershed shown as a triangular wedge on the south side of the lake. In analyzing daily Flow-weighted Mean Concentrations (FWMCs) of DRP, PP, NO₃, TKN and TSS for 2,880 samples between 2008-2016, the Lab reported encouraging decreases since 2011 in each of these measures, with the most notable reductions observed in high-flow periods during winter.*

Although suggestive that the obligatory and voluntary efforts to mitigate runoff put in place following the lake’s distressed watershed designation have had a positive effect, the authors cautioned that marked reduction in GLSM’s HNAB problems are likely to be slow in coming. Soil-test Phosphorus (STP) data from 2000-2012 indicate higher levels than almost any other sub-basin in Ohio and mean annual concentrations of all nutrients measured at the Chickasaw station remain well above Ohio EPA target baselines. Nonetheless, Laura recalls that after giving a presentation on these results, Ohio governmental officials were especially eager to hear more about the study. Even a highly qualified piece of positive news must have been a welcome ray of sunshine to regulators who likely received some push-back when mandating a suite of potentially expensive changes in land management practices within the watershed in 2011. (Just before leaving office in July 2018, Governor Kasich signed an Executive Order declaring about half of the Maumee watershed as distressed. The order, however, was never enacted.)

In 2019, the Journal of Great Lakes Research published a Commentary coauthored by six NCWQR researchers with the rather portentous tile, “Needed: Early-term adjustments for Lake Erie phosphorus target loads to address Western Basin cyanobacterial blooms.”† Unlike many of their recent papers, this one included no researchers from outside of the Lab. The article was potentially controversial, given that it recommended a reconsideration of the GLWQA Annex 4 targeted phosphorus loads to Lake Erie adopted in 2016 after years of discussion and debate The Lab appears to have determined it best to take its stand, solo.†

The problem the commentary addressed was one that had been troubling Dave Baker for some years¹⁹:

a. The importance of recognizing that the two principal components of Total Phosphorus (TP) loads entering Lake Erie—Dissolved Reactive Phosphorus (DRP) and Particulate Phosphorus)—differ significantly in their bioavailability to algae and cyanobacteria, and

*By 2016, TSS had decreased by 29%, PP by 46%, DRP by 18%, NO₃ by 19%, and TKN by 36%.
†Perhaps in line with this going-it-alone stance, the Acknowledgement section of the paper included the singular statement, “Preparation of this commentary paper did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.”
b. The GLWQA phosphorus targets do not explicitly incorporate this difference.

DRP exists in a form that is essentially 100% bioavailable (absorbable and useable by plants, algae and cyanobacteria), while only about 25% of PP has been found to be bioavailable. Thus, the Total BioAvailable Phosphorus in a water sample (TBAP) consists of all DRP and only the component of PP that is bioavailable (BAPP); i.e., TBAP = DRP + BAPP.

NCWQR data indicates that between 2008-2017, DRP accounted for just 24% of the spring total phosphorus load in samples from its Maumee River sampling station but 56% of the TBAP load, while PP comprised 76% of total phosphorus but only 44% of TBAP. But the importance of BAPP as a cause of Western Basin HNABs is further reduced by the fact that, even during storm events, substantial quantities of PP settle into bottom sediments of the River and Maumee Bay while virtually all DRP passes through the Bay and out into the Lake.\(^\text{20}\)

Baker, et al. argued that by ignoring differences in bioavailability, the 2016 targets (calling for 40% reductions in both TP and DRP) provided no guidance for choosing among different management options for ameliorating Western Basin HNABs based on their effectiveness in reducing TBAP loading into the Lake. The researchers pointed out that while agricultural fertilizer management is based on the measurement of bioavailable phosphorus in the soil (via STP measures), the environmental community has traditionally used measures of TP (which is seldom even measured by agronomists) for water quality management—even though orthophosphate (the bioavailable form of phosphorus principally measured in STPs) is also the form taken up by algae and cyanobacteria.

In an example of how different approaches to modeling can lead to strikingly different management objectives, the authors recognized that determination of the 40% TP and DRP reduction targets had been in large part based on two models that each suggested reduction in DRP to zero, alone, would be insufficient to attain the GLWQA’s mild HNAB objective for the Western Basin. However, in the assessment of Baker, et al., the failure of each of these models to find adequate phosphorus control by reduction in DRP alone was due to their improper accounting for the differences in DRP and PP bioavailability.

The NCWQR paper also presented a novel economic argument for reconsideration of the twin 40% reduction targets:

Multiple combinations of DRP and PP reductions can meet the 40% TP reduction [ranging] from 0% DRP reduction and 51% PP reduction, which results in a 24% reduction in TBAP loads, to 100% DRP reduction and 23% PP reduction, which leads to a 64% reduction in TBAP loads Similarly, multiple combinations of DRP and PP reductions can meet the 40% reduction for TBAP [ranging] from 0% DRP reduction [and] 84% PP reduction…to a 76% reduction in DRP and a 0% reduction in PP. … The agricultural community should be given the opportunity to select the most economical combinations of DRP and PP reductions for meeting the needed reduction in TBAP loading. That opportunity is largely precluded by the current formulation of target loads where both TP and DRP are given target loads of 40% reductions from 2008 base year loads.

Nutrient management by farmers is geared to the content of bioavailable phosphorus in their soils, as measured by soil tests, rather than the total phosphorus content of their soils. The same should be true for nutrient management of our rivers and lakes.
Whether the Annex 4 Task Team eventually does reformulate the 2016 GLWQA target loads to specifically consider the issues of bioavailability that Baker has long advocated merit serious consideration has yet to be determined at this writing. However the dust eventually settles, few would disagree with at least one sentence from the Recommendations section of the Commentary:

It is vital that the scientific community associated with the various constituencies speaks with one voice to the multiple communities impacting and benefiting from Lake Erie water quality.

Getting to the point where scientists can more-or-less agree on what that “one voice” should be saying to those multiple other communities about how they, together, might best address Lake Erie’s complex set of water quality challenges, is of course the name of the game.

**Fifty years is a pretty good start**

In two separate actions during the spring semester of the 2018-2019 academic year, Heidelberg’s faculty approved a new Environmental Science and Sustainability Major and a Watershed Science Specialization. While the new major restructured the University’s existing Environmental Science major to make it less focused on water studies (i.e., offering students a broader overview of topics and career options in Environmental Science), the Watershed specialization created a set of courses* and research opportunities specifically designed for undergraduates—from any major on campus—interested in water quality issues.

The Watershed specialization was modeled after the University’s Pre-Medical Concentration, which can also supplement any major on campus. Although the new specialization fits in most easily for students majoring in Environmental Science and Sustainability—they require the same background coursework for upper level courses—with adequate planning it can be completed by a student in any major. A crucial point here is that, working together, Administration and the Director of the Water Lab have found a mechanism to more fully integrate the NCWQR’s researchers into the University’s undergraduate education program.

A long-standing impediment to the University’s ability to make better use of the professional knowledge and skill sets of the Lab’s staff in teaching undergraduate courses has centered on compensation. Like Heidelberg’s Administrators, NCWQR researchers receive an annual contract, while the University’s teaching faculty are predominantly on 9-month salaries. When he directed the Lab, Ken Krieger determined what he deemed fair compensation for one of his staff members to teach a three or four-hour course. From there, he applied the hourly rate to the time involved in preparing for and teaching the course.

According to Baker, that rate of pay would inevitably be much higher than the adjunct salary Administration was generally willing to pay. For a Water Lab scientist to teach a course at that level of compensation would mean a significant pay cut with teaching added on top of a full-time job. On the other hand, if a member of the teaching faculty were to teach a three or four hour course as an overload above the typical 12-hour per semester load, s/he would generally be

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*At this writing, newly approved advanced courses in the Watershed Specialization include sophomore-level Field Methods in Watershed Science (2 hr) and Freshwater Ecology (4 hr); junior-level Wetlands (3 hr) and Watershed Hydrology (4 hr); and senior-level Watershed Management (4 hr).
paid an extra one-fourth or one-third of their assigned salary for the semester. Dave Weininger, VPAA during Krieger’s Directorship, has said that would amount to a markedly lower rate of compensation for the faculty member than the level of compensation Krieger would deem appropriate if one of his staff members were to teach a course of similar rigor.

The stalemate was overcome as one consequence of a series of discussions held between the Board of Trustees, Administration and the Lab over a period of several years—the results of which have the potential to impact much more of the NCWQR’s future within the Heidelberg community than just the extent to which its staff will be able to teach undergraduate courses.

In 2016, Administration instituted the Academic Strategic Initiative and Implementation Plan (ASIIP), a campus-wide review of all academic programs. One outcome of the review was a recommendation, approved by the Senior Leadership Team, to add a faculty line in support of Environmental Sciences. In subsequent meetings between the Environmental Science Committee chaired by Geologist Amy Berger, Bryan Smith, Dean of the School of Natural Sciences and Allied Health Sciences, and NCWQR Director Laura Johnson, an alternative suggestion was put forward—to redirect the approved funds for a new faculty line to supporting increased involvement of NCWQR staff in teaching in their areas of expertise.

The Senior Leadership Team saw potential in the proposal and the Board of Trustees, which had been discussing ways to make better use of the Lab’s professional expertise to enhance the institution’s education programs, supported the concept. Further discussions led to a compromise on the compensation issue. With their benefits largely covered through Laura’s budget, a somewhat higher rate of compensation for four NCWQR staff members* to teach a course or two each year would still amount to significant savings over the expense associated with supporting a new faculty line.

On another level, the financial arrangements enabling NCWQR staff to devote a component of their time to University-supported teaching frees up a bit of the Director’s overall budget, allowing her to reallocate soft (grant-based) funds for other pursuits. Dean Smith has referred to this as one aspect of the University’s “initial investment in developing a stable funding base” for the Lab. From the Water Lab’s earliest days, Dave Baker (and all subsequent Directors) bemoaned the fact that the facility’s ability to expand into promising new areas of investigation has been hampered by its lack of an independent, stable source of funding. The constant need for writing grant proposals and submitting reports to granting agencies, just to support existing programs, not only limited the Lab to grant-based studies but redirected staff time and energy away from the actual conduct of research. Laura further observes:

The main issue in having to cover 100% of our time with grants is that we have difficulty exploring new areas for potential research. In addition, how do we justify adding a new person with different research skills than those we already possess on staff? If we are expertised enough to write a proposal for that person, do we really need them? And if we [haven’t the skills to write a successful proposal], how do we gain the funds to support such a person?

The Board of Trustees has long been aware of this problem and has been working with Administration and the Lab to address the issue. One of the University’s key initiatives to raise the institution’s academic platform has been the $75 million, multi-year Academic

*At this writing, Rem Confesor, Nate Manning, Laura Johnson, Jake Boehler and possibly Tian Guo would be teaching.
Comprehensive Campaign for Excellence (ACCE) developed during the Administration of President Rob Huntington (2009-). Under the recently rebranded ACCE for ASIIP, the Board has approved development of a series of targeted sub-campaigns in support of areas of potential growth. One such area focuses on establishing an institutional base of support for the NCWQR.

Vice President for Administration and Business Affairs, Hoa Nguyen, has voiced strong supporter of this effort:

The future of the Lab has to be a collaboration between Administration and researchers in the Lab for it to grow and thrive. If we only stay with soft money, it will not grow.

I do not, however, see that the growth of the Lab will necessarily contribute to the overall financial revenue gain for the University, at least not in any large amount. Rather, it will create branding that will attract increased numbers of quality students to our programs. Furthermore, with pressures on water resources building throughout the world, the students we will be attracting to our water science programs will not come just from the U.S.

My challenge is to encourage the Board of Trustees to see the value of investing in the Lab not for big economic returns, directly, but in response to the question President Huntington posed on arriving at Heidelberg and with which he continues to challenge us: “Why Heidelberg?” I see the NCWQR not only as a well-established research facility lending Heidelberg credibility as a “real deal” destination for students seeking a career in environmental science, but as an important component of who we are—one of our chief attributes that distinguishes us from other institutions of higher learning.

What then, might the future hold for the NCWQR if Nguyen and Johnson’s hopes for establishing a more stable financial base for the Water Lab were to come to fruition? In an April 2019 interview, President Huntington voiced optimism for the Lab’s future and its place within the Heidelberg community:

I am bullish about the Lab’s next 50 years, and the next 5-6 years of that fifty. I have great confidence it will continue to grow and prosper. Look at its track record. Most organizations in America never last nearly so long—professional teams, rock bands, the overwhelming proportion of business ventures are lucky if they make it to ten.

From my perspective, the development of a strengthened undergraduate curriculum (and possibly a graduate program, down the road) will be a central component of the Lab’s growth. That is not to say its research programs would have to diminish as staff members take on greater teaching responsibilities. Rather I see the NCWQR’s expanding role within the Heidelberg community as an increased percentage of a larger pie.

What that “larger pie” might entail depends on whose crystal ball is being consulted and how far into the future the seer is gazing.

Much of the preceding chapter and the first section of this one discussed several of the Lab’s numerous fruitful collaborations with scientists from other institutions. No one group of researchers, for example, has exclusive access to the best data or the most useful analytical and modeling skills for attacking Lake Erie’s late-summer HNABs. Developing research partnerships so as to make the most efficient and effective use of each group’s area of expertise makes sense. In similar fashion, President Huntington sees potential for developing collaborative arrangements
between area educational institutions that emphasize each school’s strengths in preparing students for the multi-faceted careers that are evolving to meet society’s changing needs.

In March of 2018, Ohio State Representative Bill Reineke announced the Ohio State Capital Budget Office’s funding of $1 million for the newly created Ohio Partnership for Water, Industrial and Cyber Security (OPWICS). According to a release on the University’s website, as envisioned, Heidelberg University with its expertise in water, Terra Community College in industrial training, and Tiffin University in cyber-security, will be collaborating to create a state and national hub for research, education, workforce development and economic development to meet the growing needs of businesses and governments to secure natural and informational resources against human and natural attack.

The close partnership among our three institutions will create academic programming and robust field experiences that will push Tiffin, Fremont and Northwest Ohio into the forefront of cyber and water security and the protection of our natural resources at the national and global level.

The ultimate goal is that the NCWQR will be the intellectual think-tank in developing new ideas and education programs that bridge the science of water with other relevant fields such as homeland security (protecting water availability and quality), engineering, economics and sociology.

Heidelberg is to receive $700,000 of these funds (which at this writing has been approved but is still working its way through State paperwork channels) for the purchase of a tractor and applicator system to be used by the Seneca Conservation District in demonstrating to area farmers the effectiveness of subsurface fertilizer application along with instrument upgrades for the Lab.

Certainly, a successful demonstration program encouraging WLEB farmers to adopt this technology would go far to securing the health and safety of Lake Erie’s waters. However, at this point, how the three institutions may eventually collaborate in developing the academic programming to “bridge the science of water with other relevant fields such as homeland security…” remains unclear. At least the necessary first steps in establishing and funding such a relationship have been taken.

Like President Huntington, Dean of the School of Natural Sciences and Allied Sciences, Bryan Smith, sees a dynamic future for the NCWQR. He has shared that implications of the Lab’s expanding presence in national (and global) water quality research are an ongoing topic of discussion between Administration, the Board of Trustees and the Director of the Lab. Some of the issues under consideration include (in no particular order):

- Development of a “model water quality laboratory” for use in educating students in the analytical methods used in water quality research. The lab would be furnished with equipment comparable to that used by NCWQR technicians in their daily work.
- Development of graduate and/or a professional certification programs in water quality studies and/or management.
- While maintaining traditional research programs like the HTLP, expansion into other water quality-related areas of study such as pharmaceutical pollution, ecotoxicology, agricultural soil quality and water resources management.
• Expansion of the staff of researchers and technicians, with re-organization of the NCWQR into divisions focusing on different aspects of the Lab’s endeavors.

• Construction of a separate, dedicated building to house the expanded NCWQR.

As with all discussions exploring options for the future of an institution, the possibilities listed above depend on a number of enabling factors coming together. However, the fact that each of these potential futures are being seriously explored is indicative of how important to Heidelberg the Lab has come to be seen by members of the Board of Trustees and the Administration.

But at least one thing about the future of the NCWQR is seems clear—the advancing technology for the monitoring of water quality is changing the very nature of what it means to be a water quality laboratory. Laura observes that while the lab still receives one to two-thousand contract samples to analyze per year, that number is decreasing as other labs have geared up to assay their own samples. And within the past several years, the development of machines for the \textit{in situ} monitoring of many of the most commonly measured indicators of water quality has led to something of a revolution in how raw data is being collected and analyzed.

The Water Lab itself now deploys a number of YSI data sondes\textsuperscript{*} (Figure 5) at several of its HTLP sampling locations where they collect data on DO, pH, conductivity, turbidity, and temperature. Jake Boehler indicates,

\begin{center}
This data is utilized in several ways including calculating stream metabolism, determining turbidity and phosphorus relationships, as well as other specific research questions for projects focused on these parameters. The sondes are deployed for up to 90 days and then the data is downloaded, the instrument is re-calibrated and then re-deployed to collect more data. This type of equipment is allowing us to keep up-to-date with new innovative ways of collecting water quality data and provides us additional information to pair with our HTLP data.
\end{center}

\textsuperscript{*}The word “sonde” is French for “probe.” A data sonde is a machine that collects and records environmental data. YSI is a leading provider of equipment for measuring water quality; it is a brand of Xylem Analytics.
At this writing, some of the most important indicators of water quality, like the various forms of phosphorus, are not reliably measured by available sonde devices, although that may well change over the next several years. Johnson would like the Lab to reach the point where it could have many or most of its water quality assessments conducted in the field, “but we’d still have to validate our results.” Even the most reliable machines have to be checked for accuracy and consistency; the quality control that has been a hallmark of the Water Lab since its earliest days will remain so in its future.

In fact, Rem argues that the NCWQR’s in-lab quality control capabilities will take on added importance as sonde technology and prices make them more widely available to a broad diversity of organizations with an interest in knowing something about the chemical composition of water in a particular stream or river.

Everyone will be doing in situ monitoring. We will develop and maintain the standard QC procedures against which other labs will compare their results. With increased adoption of in-the-field water monitoring methods, the need for analytical laboratories with the capability to evaluate the consistency and accuracy of the data they generate will only increase.

Laura adds that in the development of sonde-based sampling methods, the USGS is a generation ahead of everyone else. However, as a governmental agency, their researchers have so much bureaucracy to deal with that the NCWQR’s prices to operate a sampling station will likely continue to make Heidelberg an attractive alternative for collecting and analyzing water samples.

And at present, “real-time data is scary. Ohio requires us to jump through so many [quality control] hoops before they will agree to use our data, that, at least for now, it would be infeasible for us to rely too heavily on data collected by in-field sensors.”

The Water Lab: monitoring, analyzing, modeling, interpreting, sharing, advising and educating

Throughout this narrative, “Water Lab” has been used as an equivalent term for the research facility that at different times has been officially titled as the Sandusky River Project (1969), the River Studies Laboratory (1974), the Water Quality Laboratory 1977) and the National Center for Water Quality Research (2002). For exactly half of the Lab’s 50 years stretching from 1969 to 2019, it was known both within Heidelberg and to the outside world by its WQL acronym. To many old-timers, that’s still the name that it wears the most comfortably.

But Water Lab may be the better, or at least more inclusive, name. The “Water Quality” of WQL really applies best to the Lab’s long-term studies of the chemical properties of water; it’s a bit of a stretch to explain how the name would also cover most of Ken Krieger’s 37 years of biological investigations (1978-2015). Then too, neither “water quality” nor the “National” of the NCWQR may encompass all of the Lab’s activities as it heads into its second span of fifty years.

In March of 2018, Confesor, Johnson and Vice President for Administration and Business Affairs, Hoa Nguyen attended Vietnam’s International Water Week workshop in Hanoi. At the conference, Rem provided an overview of the Lab’s work in a special session on U.S.-Vietnam collaboration in research. During the week they were there, a Memorandum of Understanding was signed between Heidelberg and the country’s National Center for Water Resources Planning and Investigation (NAWAPI). The agreement committed the two groups to seek funding for at least one joint research project in Vietnam and to work towards an exchange of students and faculty.
The connection initially developed from Rem’s meeting the Director of Water Resources Monitoring at NAWAPI during a 2017 ECMWF* conference in Sweden. Assuming funding can be found, the project in Vietnam that Rem envisions will likely continue his collaboration with Ali Saleh of Texas State University at Tarleton. Saleh’s overall research objective is to develop mathematical models designed to quantify soil loss and consequent water issues in developing countries. For his part, Confesor would then evaluate and validate Saleh’s models using data from those countries.

Saleh and Rem have planned a conference in the Philippines for 2020 to involve more Southeast Asian researchers in such projects. Tian Guo also has interests in working with Asian scientists, helping them learn how to adopt hydrological models in addressing their nations’ growing water resources challenges. The way Rem sees it, given the Water Lab’s extensive experience in conducting empirical and modeling studies of rivers and streams—the detailed knowledge of how to establish appropriate data collection programs, how to analyze and interpret trends in the resultant data, how to apply, evaluate and validate mathematical models of the interaction between agricultural practices and water quality, and how to communicate scientific understanding to farmers, agricultural advisors and policy makers….Given all this experience:

The Lab has the very real potential to be at the forefront of science’s efforts to address a wide range of water issues, not just here in the Great Lakes region, but across the world. Our expertise has been in water quality studies, but there are many other issues of equal or greater importance that we are well-positioned to address. The simple availability of water, for example, is of primary importance in so many parts of the planet; there’s no water quality without water.

Questions of how a limited water resource within a region is to be best used integrate a wide spectrum of factors requiring an understanding of human culture and politics, patterns of land use and its effects on water availability and quality, changing climatic conditions, and the ecology of all manner of life forms in the area. Consider, for example, the complexities involved in just one of the world’s many transboundary river systems: the Mekong River, the world’s 12th longest river, passes through China, Myanmar, Thailand, Laos, Cambodia and Vietnam. Maintaining both the quantity and quality of its water is of critical importance to millions of people.

Confesor argues there is a great need for collaborations between scientists in developed and developing countries and that the payoff for both parties in such relationships could prove immense. Rem dreams big and sees Heidelberg’s NCWQR as a potentially significant player on a global stage. How realistic is his vision? What are the Director’s thoughts on the immediate and long-term future of the Lab?

What Rem does is well-suited to a variety of applications around the globe. To the extent we can obtain adequate funding to support and expand his work, great! I am supportive. It’s difficult to see how our tributary monitoring program could be extended onto a global platform, except in an advisory capacity.

As we move forward, there is also the issue of maintaining a clear understanding of who we are as a Lab and the nature of our role [within the community of water quality research facilities]. We are a small operation housed within an undergraduate liberal arts institution with limited resources to support our work. We can’t—and don’t need to—do everything.

*Recall that the European Center for Medium-Range Weather Forecasting (ECMWF) is the organization that supported the international C3S Global Case Users study in which Rem participated.
We are in the fortunate position where we can leverage our data and the skills of our scientists and technicians so as to encourage other professionals with complementary skill sets to work with us. … By working with researchers at other institutions, we are becoming part of the scaffolding of water resources scientists that is providing the structure to more efficiently address the region’s water quality issues, both the ones we currently face and those new challenges which will surely confront us in the future.

A challenge for the future is for the Lab to stay up with technological advances in the field, to stay relevant. The Ohio EPA and the Lake Erie Commission are increasingly reliant on the raw data we provide through our HTLP and I find myself being asked by state legislators and others to offer advice on policy issues and to represent the NCWQR on all manner of advisory committees. But we are overworked, and I am learning how to say “no.”

We need to grow, to be a larger facility with a larger staff of researchers. There’s certainly enough work to support such expansion. However, like every other Director of the Lab, I feel our ability to take advantage of opportunities to move into new areas of study is hindered by our dependence on soft money. I am therefore cautiously optimistic about the recent set of discussions we’ve had with Administration and the Board of Trustees’ concerning their interest in finding a mechanism to help place the Lab on a more stable funding base. We will be very interested to see how the full picture of the institution’s financial arrangements with the NCWQR plays out over the next several years.

And, finally, back to Dave Baker

Ken Baker: Conducting the many interviews that formed the basis for this history was easily the most enjoyable part of the project. The best part was when staff members, former students, agronomists, farmers and researchers from other institutions would illustrate their appreciation for the Water Lab’s work—and for one another—with a personal story. Their perspectives invariably added a new dimension to my understanding of the Lab’s place within the scientific world and in the hearts of those who have worked in or with its staff.

The book’s final chapter briefly profiles the 65 people who had graciously taken the time to share their thoughts on the Lab. Their comments provide insights into the Lab’s five decades that could not have been obtained any other way, and I have also used many of their remarks to bring life to each of the preceding chapters.

But my own telling of the story ends with this chapter and with reference to a well-known quote from Dave Baker. When asked, as he often was, about his secret recipe for building the Water Lab, Dave would say:

In many instances we were in the right place at the right time with the right people.

For example, (a.) We were located virtually on top of the Sandusky River, one of the main tributaries to Lake Erie in the late 1960s at a time the Lake was being called “dead;” (b.) The Biology Department gave us the green light [and Administration the money] to institute a three-week river studies component to my Introductory Biology course, which (c.) subsequently gave me the data to obtain a grant for our first major study, a project investigating low-water conditions in the river during mid-summer, that (d.) was upset by the wettest summer in decades, leading to (e.) our first important discovery, a new understanding of the significance of storm events in nutrient transport.
That was perhaps the first example of David being in *the right place and the right time*; there were a lot of others. It seemed the Lab was always a few years ahead of everyone else—automating the transfer of data from their analytical machines to computer storage, measuring pollutants in groundwater and rainwater, calling attention to the importance of dissolved reactive phosphorus, bioavailable phosphorus and soil stratification, among many other instances.

And during the Lab’s first decade, the *right people* came along—Jack Kramer, Ellen Ewing, Barb Merryfield, Ken Krieger, Pete Richards; and Nancy Miller would follow just a few years later. An interesting question is, “Why did they all stay?” During the economically challenging period in the early 1980s, Heidelberg was itself in danger of shutting its doors. But by that time, David Baker and his small but highly skilled team of researchers and technicians had already put the Water Quality Lab on the map. Its reputation for producing data of exceptionally high quality together with Dave’s growing reputation in scientific circles as a forward-thinking leader meant it would not have been too difficult for Baker to have moved the entire operation to a well-funded Division I research institution.

But he did not relocate the Lab. Things were tight again in the 1990s and, really, finding the funds to keep the Lab afloat has been an issue throughout its entire history. With the staff’s professional skill set and impressive record of successful research, it would seem to have been the reasonable thing to leave Heidelberg for greener pastures at Michigan or some other welcoming research group. But again, it didn’t happen, and more than a few researchers I interviewed have wondered why not?

Ellen Ewing’s take on the answer to that question seems closest to home. “You will not find any Heidelberg alumni more committed to the institution than Dave and Peg Baker.” That simple statement has the ring of truth to it, although it doesn’t indicate why it should be so. But for whatever reason, the fact remains that the National Center for Water Quality Research and its several predecessors in name, has been an integral part of the Heidelberg community.

It therefore seems an opportune moment, as the NCWQR celebrates its golden anniversary in 2019, to recognize that when it sees its diamond anniversary in another ten years, it will be doing so with a new generation of highly skilled researchers and technicians. What will then be the nature of their connection to Heidelberg University? Here’s David Baker one more time:

The future quality of life in this area will depend on how well we use the land to produce the food, fiber and energy we need while at the same time minimizing [negative] effects on water resources. The Lab has some unique insights and data sets pertaining to these issues and I hope for a solid future for the Lab, moving ahead.

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*There’s a picture in the center photo section of Dave and Peg toasting her 50th class reunion in 2010.*


King, K. 2017. Evaluating the 4R Nutrient Stewardship Concept and Certification Program in the Western Lake Erie Basin: Annual Report to the International Plant Nutrition Institute


Chapter 6. Five Takes on the Water Lab

The story of an institution can be told from a variety of perspectives—from that of the principals who founded and directed its activities, from that of the staff who carried out the Directors’ agendas, and from that of those outside the institution who can speak to its work and place in society. In 65 interviews with a diversity of researchers, former students, agriculturalists and others familiar with the Lab, the most commonly voiced sentiment was admiration—sometimes tinged with amazement—for the Water Lab’s staff and the invaluable data it has amassed over the past fifty years. For convenience, their perspectives are organized here into five categories: researchers from other institutions, farmers and agricultural advisors, Heidelberg faculty unaffiliated with the Lab, student research assistants and Water Lab staff members. Although a special effort was made to interview those with intimate knowledge of the Lab from decades past, a number of former staff members who had played important roles in its operation for several years could, unfortunately, not be reached.

Researchers from other institutions

On his retirement, Baker received a number of letters of congratulations from colleagues from other institutions with whom he had worked over the years. One note neatly summarized how the Water Lab under Dave’s leadership had changed many researchers’ views on the caliber of work that can come out of a small, liberal arts college. Fred Swader, USDA National Program Leader for Water Resources and Cynthia Garman-Squier Coordinator for Environmental Management and Agricultural Chemicals in Washington DC, wrote:

I must admit that there was some skepticism among many here in USDA regarding a professor from Heidelberg! After all, that isn’t even an experiment station of the Ohio State University. And, generally we were not disposed toward favorable opinions of either private colleges or their professors. Well you sure changed that!

…I also remember much of the original USDA water quality work was funded from a Congressional concern about drinking water quality in, and a result of, the Corn Belt. We never suggested that we could or would improve the quality of the groundwater in the Corn Belt, because we had serious doubts about the extent and severity of the presumed problem.

At the same time, we could not justify spending the USDA budget to document the parameters of the problem. But your project with the Farm Bureau did! And we both know the results! And so do most people associated with either agriculture or water quality! No one in water quality now asks, “Where’s Heidelberg University?” or “Who is David Baker!”

This change in perspective took some time to develop. Dave remembers that early on, the Chair of the Ohio State University’s Department of Agriculture downplayed some of the Lab’s results, but such denials didn’t last long. However, the massive amount of data compiled by the Water Lab would not have, by itself, been enough to convince other researchers to take its work seriously. The data had to be of very high quality and from the outset, quality control has been
central to the Lab’s operation. All studies were performed in replicate, with repetition sampling and continual back-checking against known standards. And long before other laboratories were able to do so, Jack Kramer found ways to minimize human error by automating much of the Lab’s analytic chemistry and the transfer of data to computer files.

“In fact,” observes former Director of Sea Grant Ohio, Jeff Reutter, “you hear the lab’s methods referred to as gold standards for sampling around the Great Lakes.” Again, this attitude didn’t develop overnight. In the mid-1970s the US Geological Survey discovered that some of the Water Lab’s reports on pollutants in riverine systems contradicted their own results. It seemed to them that Baker’s group had greatly overestimated phosphorus concentrations. The Columbus office sent a representative to Heidelberg to learn where the Lab’s methods were faulty but could find no problems with its procedures. In turn, Dave asked to see the USGS’s methods. A couple of days later Dave and Jack caught each other’s eye passing in the hallway. Independently, they had each discovered that the governmental agency had incorporated a mathematical error in its analyses. Unfortunately, the error was not correctable, and it invalidated twenty years of USGS data on phosphorus.

Reutter also singled out two of the Lab’s features that had together distinguished it from other research facilities, regardless of size: Baker’s ability to somehow find the necessary funding for the Lab’s long-term tributary monitoring studies, and the excellence and collegiality of its staff.

One thing everyone agrees on is the importance of long-term monitoring but getting the funding to do so is extremely difficult. The fact that Dave has been able to find the funds—from a wide variety of sources—to support the Lab’s high quality work is a tribute to his persistence and success.

The Lab’s data sets have provided an invaluable baseline from which to make critical management decisions. For example, for ANNEX 4 we relied on Water Lab data in determining what our targets should be; how nutrient load standards should vary with weather, seasons, soil and cropping patterns within a watershed.

Tied in with this is the caliber of the staff and researchers who have worked with him, his long-term technicians and researchers, especially Ken Krieger and Pete Richards. Pete, for example, would never embellish the importance of his own work. He was very straightforward and clear in conveying often complex material.

Perhaps the part that surprises me the most is that Dave was able to establish, grow and maintain the lab at Heidelberg without the assistance of graduate students. [In fact] the caliber and importance of work regularly coming from the Lab led Ohio Sea Grant to modify some of its approach to awarding support for projects. An important objective had been to promote the development of graduate students, but Heidelberg College had none. So to support the Lab’s important work, the development of undergraduate researchers played more of a role.

Chris Winslow, Reutter’s replacement as Ohio Sea Grant Director on Jeff’s retirement, echoed both of these points:

I can’t think of many states that have as comprehensive and robust a data set on tributary water quality and nutrient loading as Ohio. A lot of what we can recommend [to farmers] is based on our understanding, from Heidelberg University’s baseline data set, of what would be a reasonable target to shoot for.
The collegiality of the folks working in the lab has been one of its seminal features. Rather than guarding their methods, data and insights, they have made these freely available to other researchers and the general public. Of special note, they’ve looked for ways to build partnerships, to collaborate with others working on similar issues for the greater good.

Norm Fausey, Research Leader and Supervisory Research Soil Scientist at USDA’s OSU Agriculture Research Service (ARS) in Columbus typically works on environmental issues of national concern. He offered an interesting take on the unique relationship between funding, staff proficiencies and the research program that developed at Heidelberg:

I come from the perspective that appropriated funding is a prerequisite to work. Dave Baker, however, initially had no money. To gain funding, you need some results. It’s a real tribute to Dave that he was able to [initiate and] sustain his program. A lot of the credit must go to the dedication and cohesion of his staff. Jack Kramer set up and maintained the Lab’s complicated sampling and analytics programs and Pete Richard’s statistical perspective enabled him to identify important trends in the data. Also, give some credit to Ken Krieger who righted the ship again after some rocky leadership times.

Although Fausey never worked directly with the Lab on a specific project, like many other researchers working on agroecosystem topics, he felt he’d nonetheless benefitted from Baker’s input on advisory committees.

David was a driving force for the development of the International Joint Commission’s Great Lakes Water Quality Agreement. It wouldn’t have come into being without Dave’s input and the data produced by his Lab.

While David focused on rivers, I focused on land and the edges of land. You need both and he made me aware of the interactions between land and water.

National Wildlife Federation’s Great Lakes Director, Gail Hesse, tells a similar story of Baker’s ability to make things happen. In 2006, Dave approached her about the Lab’s observations on the extent of dissolved reactive phosphates entering Lake Erie and its impact on the resurgence of algae in the Lake. She remembers him asking, “Gail, what are we going to do about this?” It was his suggestion to assemble the Ohio Lake Erie Phosphorus Task Force, which published its first report in 2010 giving Ohio a leg up in understanding what was going on—before the crisis years of the major algal blooms in the western basin. David subsequently wrote and received a USEPA grant to convene a second Task Force and he served on the committee that created the Great Lakes Water Quality Agreement ANNEX 4 reduction targets.

Gail is on the same page as many other water quality researchers and modelers in her belief that the challenge now is how to best integrate agroecosystem and watershed sciences with farming practices and land management throughout the Lake Erie Basin.

Most farmers are doing what they’ve been told to do but it’s time to do something different. The question is how much do we need to know before we act? We all want to act with a degree of certainty, but when will we believe we have reached the necessary level of understanding to move forward decisively?
It’s going to come down to individual fields. We need to know what’s happening in the water as well as on land, and we need an understanding of farmers’ attitudes for it all to come together.

Farmer attitudes is an area of Robyn Wilson’s research interest. As an Associate Professor of Risk Analysis and Decision Science at the Ohio State University, she has conducted three surveys of farmers in the Maumee watershed since 2011. Overall, her studies have led her to an upbeat view of farmers’ willingness to modify their land management practices in helping to address water quality problems in Northwest Ohio.

Yes there’s grumbling among farmers about other sources of phosphorus flowing into Lake Erie tributaries—raw sewage from combined sewage overflow systems, breached septic systems, lawn fertilizer runoff, airborne particles—and harsh complaints from a vocal minority. However my surveys indicate 70-80% of area farmers are concerned, aware, and feel partly responsible [for the region’s water quality problems]. The majority are willing to do something. This is encouraging since most effective management scenarios from modelers suggest only 70% farmer involvement is needed to effect adequate change in receiving waters.

The problem is that most farmers are not fully convinced that methods promoted by scientists and agricultural advisors will sufficiently address the region’s prevailing water pollution difficulties. Robyn has found that while most farmers are motivated to do something, if only to avoid regulation, they’ve experienced a lot of conflicting suggestions on what that “something” should be.

One day they hear cover crops will save the world, and the next a different set of credentialed professionals explain that dissolved reactive phosphorus is the issue. Until we come up with a consistent message, farmers will feel they have reason to hold their fire. Science just isn’t there, yet. It has to get its act together.

Like Gail Hesse, she suspects modeling at the level of the individual field may provide the best opportunity to effect significant change in land management regimes within the region.

Though of pivotal importance, the Water Lab’s data is still but one piece of the puzzle. The work of Kevin King, Research Leader and Supervisory Research Soil Scientist at USDA ARS, Columbus, has focused on “understanding complex watershed scale interactions of weather, soil, water, plants and land use management on hydrologic processes and their relationship to water chemistry.” His unit has partnered with Heidelberg’s Lab on various projects including the Agency’s Long-term Agroecosystem Research (LTAR) Network, Eastern Corn Belt Node.

From the work I do and from an Ohio perspective, Heidelberg’s data is invaluable. The Lab has [long been] collecting data for questions that had not yet even been considered. If it hadn’t been for that data, we’d be floundering around on Lake Erie issues.

Even with all the new technologies we’re seeing, they still won’t replace actually going out to collect samples. We will still need ground-truthing. Over the next 20-50 years, the Lab will remain vital to Ohio’s waters.

That said, King, like several of the agronomists mentioned below, disagrees with some of Baker’s interpretations of available data:
I don’t think that phosphorus stratification is as big an issue as Dave does. For one thing, there are available technologies for subsurface placement. But there are other issues. Soil health—its chemical and biological quality—is a missing link. We don’t know how important it is yet.

Unfortunately, but perhaps understandably, a chemical industry representative whose company had financially supported some of the Lab’s pesticide studies and who is himself a water quality researcher familiar with the Lab’s work declined to be interviewed after reviewing a list of proposed questions. He, and the company’s lawyers, felt anything he might be quoted as saying had the potential to be taken out of context and used to the company’s disadvantage by anti-agrichemical activists.

**Agricultural advisors and farmers**

*Beth Diesch* is the Team Leader and *Bret Margraf* a Nutrient Technician and Business Leader with the Seneca Conservation District, Ohio Department of Agriculture, Division of Soil and Water Conservation. Bret observes that because of the District’s work with the NCWQR, the SCD’s knowledge base is far different from that of any other District in Ohio. “There’s nothing more valuable than high quality information coming out of your own backyard.” And that understanding is reflected in the improved insights and land management options Diesch’s technicians can share with area farmers.

Interestingly, Dave Baker views this situation as emblematic of one of the more significant challenges facing the scientific community in effecting meaningful change in land management practices within the Lake Erie watershed. Where agricultural extension agents and other trusted advisors are insufficiently versed in current research on the complex relationships between land management and off-site water quality, they cannot be expected to help farmers fully understand the consequences of the various options available to them.

The District’s bond with the Water Lab was forged in the 2008 EPA-sponsored Targeted Watershed Study on Honey Creek and further strengthened that year when the District initiated a 5-year collaboration with the Lab collecting soil samples from four counties as part of Baker’s grant for the phosphorus stratification study. Even so, Diesch and Margraf, like Kevin King, disagree to some extent with Baker’s emphasis on phosphorus stratification as a key feature to be addressed in the management of agricultural fields. Diesch notes,

> We don’t have a silver bullet or even a package of silver bullets. What we have to discuss with our farmers are a series of risk factors. Fields vary greatly in phosphorus concentrations. If phosphorus stratification is relatively low on a given field, the deficits associated with inversion tillage (from destroying cover protection over soils) will outweigh the benefits. On the other hand, periodic inversion tillage may be useful if stratification is high.

Again like King, Margraf argues that too little attention has been given to the relationship between soil health and water quality.* Nutrients in the soil are not directly available to plants but are made more or less accessible via the extent of biological activity surrounding their roots.

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*NCWQR Director Laura Johnson addresses soil health concerns later in this chapter.*
We used to think of worms when discussing important biological interactions in the soil. But we now understand that the ecological interplay of insects, fungi and microorganisms are also a critical component of a soil’s health.

We would love to see the Water Lab take on a biologist who could evaluate the biological aspects of soil health as a component of its water quality studies.

Beth and Bret were also less optimistic than Robyn Wilson that area farmers would voluntarily adopt significant changes in their land management practices to better the region’s water quality. Perhaps their years of work in the trenches, their daily interactions with a wide diversity of personalities, had made them a bit cynical, but Beth nodded in agreement when Bret observed that “A good proportion of farmers aren’t too worried about fertilizer runoff. Very few really care about it…” though he added that their awareness of the issue had increased markedly after the media blitz following the 2014 hazardous algal bloom impacting Toledo’s water supply.

OSU Extension Agent Greg LaBarge has been working with farmers on pulling together the contributions of various disciplines in assembling economically and environmentally responsible crop systems. He has a somewhat different perspective on farmers’ views.

Farmers want to take full responsibility for what they have control over, but how much of our nonpoint pollution problems are due to larger scale issues over which they have no control? They are willing to adopt new management practices as they become available—within acceptable budgetary parameters.

This brings to mind a point Kevin King has made.

You sometimes hear agronomists say you’ve got two chances to make a significant difference in farmers’ lives. A major investment in retooling running $250,000 or more will be a consideration for many farmers only twice in a career.

Monetary concerns figure into farmers’ willingness to modify their practices in many ways. Retired Fremont, OH Sunrise Cooperative Agronomist Jerry Cunningham refers to the financial challenges facing the farmer interested in maintaining cover crops for his or her operation:

The guy who’s not used cover crops before can get government support, but not the fellow who’s already there. You know it’s of value but they [governmental agencies] are not paying for established practice. They did the same thing with buffer strips.

Jerry, like Robyn Wilson, also points to confusion engendered by shifting and sometimes conflicting scientific perspectives on Best Management Practices.

We used to say phosphorus doesn’t move in the soil, but we should’ve known that it does. I told my farmers for 25 years that it remains stable in the soil. I was the Kevin King for my farmers.

But agronomists are evolving in their understanding. Right after the Toledo fiasco, the 4R thing* came into play. The Nature Conservancy already had it set beforehand, so it was ready to go virtually the day after.

*From the Nature Conservancy’s website: “To help solve the problem of excess nutrients in our waters, the 4R Nutrient Stewardship Certification Program was created. The 4R Program, created by the agricultural industry,
Greg LaBarge adds that the cycling of phosphorus within Lake Erie watersheds is still incompletely understood. The fates of its various fractions within the soil is still unclear.

This confusion over shifting perspectives on the role of phosphorus in its various forms within the Lake Erie watershed and over how its management might impact farming practices is understandable. The US Action Plan for Lake Erie speaks directly to the challenges involved in reorienting the thinking of researchers, agronomists and farmers about the nutrient:

…For example, adding focus to dissolved rather than particulate phosphorus is a major paradigm shift for most agricultural conservation programs which have traditionally focused on preventing soil erosion. Likewise, traditional programs to address waters impaired by nutrients through water quality monitoring, assessments, TMDLs, and implementation of point and nonpoint source controls have historically focused on controlling sediment-bound nutrients or dissolved nitrate in groundwater…The idea that we need to control the more bioavailable forms of phosphorus has not been on the radar for long, and in many cases our first step will be to start collecting SRP data.

One thing upon which all agronomists and farmers interviewed agree is the importance of educating and involving farmers in land management decision-making processes. Beth Diesch says that connecting with people is critical to avoid divisiveness when farmers are confronted with mixed messages or, worse, misinformation. Social science communication skills are needed along with the hard sciences data. Kurt Dunn, a member of the Seneca County Farm Bureau and the Sandusky River Watershed Coalition is committed to environmentally responsible agriculture, but he has concerns over the potential for excessive governmental regulation:

Farmers are now required to obtain Fertilizer Certification Licensure, but we don’t want the government further telling us what to put on our fields and how much. Conditions differ from plot to plot and one size does not fit all. We appreciate the help we get from our cooperatives and try to follow their advice—4R Stewardship, grid sampling and planting more cover crops. There are definitely more guys planting cover, but it’s expensive. Some level of financial assistance might encourage more farmers to plant fall cover.

In addition to farming his own acreage, Doug Busdeker, before retiring, had managed the Anderson’s Retail Farm Stores and served for two terms on the International Joint Commission. One of his chief concerns is the disconnect between the agricultural community and much of the rest of society.

People not associated with farming have little understanding of the conservation practices most farmers incorporate in their work. Yes, there are a few bad actors, but they are few and far between. Most of us are applying fertilizers according to Land Grant University recommendations.

It doesn’t help that the news media seems to have an anti-agriculture bias. When you listen to the news on Toledo stations, all you hear is problems with farmers and livestock operations.

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state agri-business associations, The Nature Conservancy, The Ohio State University, Michigan State University, state farm bureaus, state agencies and others, encourages agricultural nutrient service providers to adopt proven best practices through the 4Rs, which refers to using the Right Source of Nutrients at the Right Rate and Right Time in the Right Place. This voluntary program provides a consistent, recognized standard for nutrient service providers in Indiana, Michigan and Ohio where surrounding waters drain into Lake Erie.”
One large scale farmer managing several thousands of acres in Seneca County expressed similar feelings. In fact, his concern over the public perception of farmers as a principal cause of pollution was such that he only agreed to be interviewed if his name was withheld.

I find it frustrating that the challenges facing modern farmers and our efforts to deal with those challenges are not well understood by the rest of society. With only 1.7-1.8% of the American public directly involved in farming, our platform is limited. It doesn’t help that we tend to be quiet. We need to do a better job of explaining ourselves when given the opportunity.

Farmers are still trusted, and we can’t afford to lose that trust. We are aware of inputs into area streams due to our practices and most of us—there are a few bad apples—are performing due diligence in adopting BMPs. Unfortunately, due diligence is hard to demonstrate.

On a positive note for the NCWQR, everyone interviewed for this section had high praise for the Lab’s work and its staff. Laura Johnson, in particular was often applauded for her abilities to communicate clearly and respectfully with a wide array of audiences. Kurt Dunn, for example, said he is always interested in hearing from her. He views her descriptions of new developments from year to year as coherent and informative. It seemed all would agree with Greg LaBarge’s assessment at the conclusion of his interview: “The Lab is in good hands with Laura, these days.”

**Heidelberg faculty unaffiliated with the Lab**

On discussing the retirement of long-time Biology Professor Arthur G. McQuate in the *Teaching of Natural Sciences at Heidelberg College*³, the history George Barlow co-wrote with Ron Stuckey, Barlow wrote:

One more legacy was bequeathed to the Biology Department by Professor McQuate before he retired in 1966. For years he had taught the freshman biology program with unremitting enthusiasm, and now he sought a new member of the department to take on that task, and additionally, to teach plant physiology. David B. Baker ’58 would be that person.

As discussed in Chapter 1, hopes were high that Baker would indeed prove the ideal candidate to fill McQuate’s over-sized shoes. Of the entering freshman class of 390 students during Dave’s first year of employment, fully 241—62%—were enrolled in Baker’s Introductory Principles of Biology course. Although other Biology faculty would teach many of the laboratory sections, it was expected that David, who had taken McQuate’s course as an undergraduate, would follow in his predecessor’s footsteps by shouldering the lion’s share of the heavy teaching load.

_Percy Lilly_, who chaired the Biology Department from 1964-73, had jumped at the chance to hire Baker. Percy recalls one of the Science faculty’s regular Wednesday sack lunch get-togethers. At that time, the Tiffin sewage treatment plant, about two miles north of town, only had primary sewage treatment; when the wind was out of the north you could smell the plant’s outflow in town. Knowing that the facility was soon to install secondary treatment, the lunchtime discussion centered on the opportunity for having students conduct a before-and-after study. Dave and Chemistry’s Tom Taylor apparently picked up on the idea.
The Biology Department liked the 3-week Introductory Biology River Labs sequence that began with the fall semester of 1967. But the data generated by the students also enabled Baker to successfully compete for his first major water research grant, the $47,650 FWPCA Augmented Flow study that allowed him to hire Jack Kramer and establish the Sandusky River Project in 1969. However, by the early 1970s it was clear that the river work was absorbing a lot of Dave’s time and energy, and that did cause some friction within the Department and not a little anxiety for Lilly as Chair.

David was granted a year-long sabbatical for the 1973-74 academic year to further develop the Lab’s research programs and the Department hired Gayle Joyce to take over much of the teaching of his Introductory Biology. On Baker’s return, with research and grant writing taking ever more of his time, Dave essentially became full-time committed to the Water Lab, only teaching his Plant Physiology on an alternate year basis. But soon enough he had to give up even that much teaching and Barlow (the Department’s Anatomy and Physiology professor) felt compelled to work some of the material from that course into his own Comparative Physiology.

Then too, Physics and Chemistry were less than pleased when the Lab’s pressing need to expand beyond its initial 600 sq ft of space in Laird Hall led Baker to ask questions about unused storage areas in the basement of Bareis Hall. Both Departments had entertained their own thoughts on how they might use those rooms. Still, Dave’s research was now bringing significant funds to Heidelberg and lending a new level of prestige to the institution’s science programs. Administration approved the River Studies Lab’s move to Bareis in 1976.

Yes there were some tensions early on, but both Barlow and Lilly recall they were always addressed in a straightforward fashion with courtesy and respect on all sides. In any case, by the end of its first decade, the Lab’s position within the Sciences was firmly established and broadly valued. A different issue was the seeming invisibility of the Laboratory to the rest of Campus. Buried in the basement of Laird and then Bareis Hall until relocated to the top floor of the newly built Gillmor Hall in 2005, most faculty members outside of the Sciences knew little about the Lab beyond the fact that its staff worked on water issues in the environment.

In the early 2000s, Associate Vice President for Academic Administration Vicki Ohl was still a Professor of Theory and Music in the Music Department housed in Brenneman Hall on the other side of Heidelberg’s small campus. She recalls:

Although it’s fair to say the Lab was viewed positively, it was always this mystery. We knew they were doing big work, they got national funding, they got the penthouse at the top of Gillmor. One year, David Baker was keynote speaker for Mindscape. I was astounded; impressed by the amount of information the Lab had generated, the frequency with which its staff collected samples, the competitive grants Dave and his colleagues had received, and the fact that virtually all of the Lab’s data and insights were freely shared with any who requested them.

The Lab’s mission was to make the world a better place and this had a lot to do with the deep commitment of the staff to Dave and the Lab’s work.

*Mindscape, now known as Minds at Work, is Heidelberg’s long-standing undergraduate research conference.
One of the few faculty members outside of the sciences who did have a knowledgeable sense of the Lab’s undertakings was Bill Wickham, long-time Chair of the Business Department. Coming from a scientific background himself, Bill had a strong appreciation for the Lab’s work, often serving as the outside member on its search committees for new hires. Bill’s assessment, based on both his science and business backgrounds: “The Lab was doing things right.”

Wickham agreed with Ohl who, speaking from the perspective of her years as an Administrator, commented on a problem that was also identified by other Heidelberg faculty members. Over the years, it has proven surprisingly difficult to find a way to integrate the Lab’s programs and researchers into the University’s science curricula. Given that the roots of the Water Lab came out of a series of laboratory exercises in a freshman biology course, it seems odd that the problem has proven so intractable. David Weininger who served as the University’s Provost from 2007-2014, has said the sticking point has in part centered on compensation for teaching.

If a member of the (non-NCWQR) teaching faculty were to teach a three or four hour course as an overload above the typical 12-hour per semester load, s/he would generally be paid an extra one-fourth or one-third of their assigned salary for the semester. Weininger has said that would amount to a markedly lower rate of compensation for the faculty member than the level of compensation that various Directors deemed appropriate if one of his staff members were to teach a course of similar rigor (based on conversion of their annual salary to an hourly wage). He added it would not be perceived by the general faculty as fair compensation to remunerate Water Lab staff at a higher rate for the same level of teaching responsibilities as other members of the campus community. Although, over the years, the Provost had found ways to bend the rules to a degree—Ken Krieger was able to teach courses in Freshwater Ecology, Limnology and Water Pollution Biology in the University’s Water Resources major—it was not a permanent solution to the problem.

In 2019, however, Heidelberg’s faculty approved the newly created Environmental Science and Sustainability major along with a Watershed Science Specialization (available to students in any major). A significant component of the new programs is that a number of their courses are to be taught by NCWQR staff members. The Lab’s Laura Johnson, working together with VPAA Beth Schwartz Livingston, Vice President for Administration & Business Affairs Hoa Nguyen, and Dean of the School of Natural Sciences & Allied Health Services Bryan Smith, was able to work out a compromise that has seemingly addressed this long-standing problem.

Like many small liberal arts colleges, Heidelberg has a long history of having to weather periods of significant financial challenges. As noted in Chapter 3, during the 1980s, the institution transitioned through a particularly rough spell and President William Cassell, who had been tasked by the Board of Trustees to bring the College back into fiscal health, had levied indirect costs on the Lab’s salaries, wages and fringe benefits of 59%, which commonly imbalanced its annual budget. Gary Bryenton joined the Board of Trustees in 1989. He recalls this troubled period of time:

During the era of the College’s most difficult financial challenges, President Cassell did indeed put undue strain on the WQL. But recognizing how important it was to the College and its students, the dedication and professionalism of its founders, and the prominence it could achieve if permitted to continue developing, the Board of Trustees pushed back and challenged President
Cassell to find ways to keep the Lab going…These were difficult years for the College in general, and for the Lab in particular. But for the valuable work being done by the Lab, and its ardent support by the Board, it probably would not have survived to become the “National Center” it is today.

The support of the Board of Trustees has been essential to the development and longevity of the Water Lab. The advancement of the Lab’s national reputation and the construction of Gillmor Hall are examples of its activities. Bryenton summarizes the view shared by most Trustees and illustrates two of its more important actions:

I, along with many of the other Trustees, consider the NCWQR to be one of Heidelberg’s greatest assets, and one that deserves far more national involvement than it has been able to achieve in its first fifty years…From the outset, the WQL was highly regarded by the Board of Trustees, not only because of its unique work, but primarily because of its leadership by Dave Baker.

During my tenure as Board Chair, we had the good fortune of having Karen Gillmor on our Board. This in turn led to her now late husband, Congressman Paul E. Gillmor, sponsoring a resolution to the U.S. House of Representatives to name and recognize the WQL as “The National Center for Water Quality Research.”

…In the early years, the Lab was housed in the basement of the old science building. The Board of Trustees was well aware of the need to have such an important part of the science program at Heidelberg occupy a more desirable and prominent location on campus. Again, the Board turned to the Gillmors for their assistance. Through the generous efforts of Karen Gillmor on our Board and Paul Gillmor in the U.S. House of Representatives, Heidelberg became the beneficiary of an effort to raise funds which ultimately led to the construction of a new home for the WQL.

There is no doubt in my mind that the Lab played a pivotal role in the minds of the Trustees, alumni, friends and the college administration leading to the construction of Gillmor Hall.

As the NCWQR was increasingly gaining a national reputation for its research, many of the more business-minded Board members began to urge the Administration to explore ways to better market the program and look for opportunities to monetize its resources. Former Board member David Drake (2008-17) recalls:

Board interest in the Water Lab grew when several trustees with a business background saw entrepreneurial potential…We discussed the potential for the Lab to be a profit center for the University.

In 2012 there was a strong push from within the Board to develop Lab products and services, sell data reports and market the NCWQR. The thought was that the Lab would not only be able to stand alone but would be able to bring in a profit which would spin off to the University…Board interest blossomed then imploded when we learned that the NCWQR was funded by grants and its extensive data should be shared with peers, not sold. This pretty much squelched discussion for using the Lab as an income producing entity.

Although Heidelberg has been unable to find a way to monetize the research products of NCWQR, it has nonetheless played an important role in the institution’s ability to raise funds. Lee Martin, who worked for many years with the Alumni Office’s University Advancement and Marketing team, had this to say about the Lab’s usefulness in his work:
The Water Lab has been a gateway to a lot of gifts; it has helped give credibility to Heidelberg as a “real deal” institution of higher learning. More generally, alumni always bring the Lab up in discussion. Often, they may not have been able to tell you much about it, but everyone knew it was special. I have worked successfully on various Development projects with Dave, Ken and Pete. Dave, especially, has proven the ultimate aide in fundraising; his integrity, sincerity and passion come across especially well in small groups.

In the fund-raising plan for Gillmor Hall, naming rights were provided to donors based on their interests and the size of their donations. Most of the rooms and public areas in Gillmor Hall have signs indicating donors’ names. The donation of Board of Trustees member Ralph Talmage (2006-present) toward the third floor laboratories of the NCWQR entitled him to assign a name to that floor. He chose to name this area “The David B. Baker Environmental Research Laboratory” in recognition of Dave’s roll in founding the Lab’s water research programs.” As Dave’s brother-in-law (he married Peg’s sister, Joan), Ralph has a somewhat different perspective on Baker’s personality and career than most of those who have worked with him.

Given the amount of time and energy Dave has devoted to founding and building up the Lab, he has more than earned the right to be recognized by having his name permanently attached to the laboratories on the Third floor. I would share a story illustrating how his assertiveness is not just a characteristic of his working life, but a facet of his personality that has shown itself in other aspects of life as well. Peg and Joan’s mother was moving to a smaller house and the family had gathered at Dave’s place on Riverside Drive for a yard sale. Seemingly out of nowhere, a large goose came charging right at Joan, scaring the daylights out of her. Dave grabbed an ironing board and ran at the goose, chasing it away. We later heard the crazy bird had made the local newspaper for terrorizing several other groups around Tiffin. In gratitude, Joan later created the Gander Award plaque in his name, which I believe he still has somewhere around the house.

Given the Lab’s national reputation, Talmage, like many others at Heidelberg, has been baffled by the University’s apparent difficulty in attracting large numbers of students interested in environmental careers to the various majors the institution has offered over the past decades. Looking to the future, he has brought forward for discussion the possibility of creating a Water Laboratory Management major designed to train the next generation of technicians working in the nation’s numerous sewage treatment and drinking water distribution facilities.

Student research assistants

To a person, each of the interviewed student research assistants who had worked in the Water Lab for an extended period had high praise for the experience. The two most commonly voiced themes were the warm, supportive camaraderie of the staff and that the importance of the knowledge and skills gained through participating in the Lab’s research projects in advancing their careers after graduating from Heidelberg.

*Dave Baker notes that, “I could accept having my name attached to the physical facilities housing the Lab, but I did not want my name on its research program because the NCWQR is definitely a ‘we’ effort.”
Clint Beckert and Mark Peoples were among the first students to have worked as part-time employees in the River Lab. Like Gail (Hemsoth) Wolfe, who worked in the Lab full time for a year after graduating, they had been turned on to science by the River Labs sequence of Baker’s Introductory Biology course. All three graduated in 1974. Clint eventually received a doctorate in civil engineering and rose to become Chief of the Water Quality and Sediment section of the US Corp of Engineers, Rock Island District IL. In 1973 he worked on an NSF-funded Student Originated Studies (SOS) grant obtained by another student and after graduating worked as a technician for a year in the Lab.

The work was basically the foundation of my career. It allowed me to see first-hand applications of science class work to real-world issues. I was so impressed by Jack Kramer; he was a master of all trades—electrician, electronics engineer, chemist.

Even though it’s been 40+ years, some of those memories are quite vivid. The morning crew would ride out to the sampling sites. I remember the old VW van we used to drive; for many of us, it was our first encounter with a manual transmission stick shift. That was an experience. The afternoon crew analyzed the samples and worked up the data. There was no automation in the Lab then, so all data had to be hand-entered into the mainframe.

All of us were poor. We were so grateful when Dave and Peg Baker would invite us over to dinner at their place.

Gail grew up in Clyde Ohio, a small town about 20 miles from Tiffin. Although fascinated by the life in and around her family’s 5-acre pond, she was unaware of the Lab’s existence when she came to Heidelberg. A History major with a Biology minor, she attributes her lifelong interest in nature to her year (1974-5) working as a technician in the Lab:

Dr. Baker had confidence in us. He asked me to look at a number of failing septic systems in Seneca County and my work on that and other projects turned me into a lifelong environmentalist and conservationist. There was an atmosphere of respect and camaraderie in the Lab that I liked very much. It wasn’t yet the famous research facility it was to become, but it was very interesting work.

Many years later I remembered my year in the Lab when I organized a set of water study exercises for a mixed-age group of GED students at Lane Community College in Eugene, Oregon. I’d have never tackled what proved to be a very successful activity for the students had it not been for my hands-on experiences working for Dave Baker.

Mark Peeples became a highly successful and respected researcher and professor of Pediatrics and Molecular & Cellular Biochemistry at The Ohio State University College of Medicine. His studies on respiratory syncytial virus (RSV), a major pathogen of infants and the elderly, has helped put scientists on the road towards developing protective vaccines and antiviral drugs. Like Clint Beckert, Mark worked on another student’s NSF SOS project following his sophomore year at Heidelberg and was co-administrator on his own project in the summer following his junior year. Presenting his results at an American Association for the Advancement of Science meeting in Washington during his senior year was a pivotal experience that solidified his interests in research.

The first summer I worked with a guy from Denison and another from Kenyon University on a project designed by Heidelberg student Greg Watts and Harvard student Rick Noss (son of
Heidelberg Philosophy professor, David Noss). We were interested in the microbiology and chemistry of the Sandusky River, downstream from the sewage treatment plant in Upper Sandusky, OH. My study with Mark Fry during the second summer expanded on that study, adding a survey of benthic macroinvertebrates and developing a questionnaire exploring local residents’ opinions on the river.

Both summers were fantastic experiences. The opportunity to ask and address my own questions with projects of my own design was seminal. We all lived together during the summer, taking care of ourselves and each other. Many of us went into the environmental sciences. John Stasco worked for Ohio EPA, Meridith Kemp became a forester in Washington State. Some years after she graduated, Janice Beyerle, who had studied clams, drowned in a skating accident in Boston. I started an endowment for undergraduate research in her name.

Jack Kramer was The Man. Forever in the Lab, he was always willing to talk about our gear; he was absolutely fearless about the technology. And despite his generally disagreeable demeanor (which he cultivated) he was very encouraging to work with.

Dave Baker was working on a higher level; he was thinking about what all this data meant. He didn’t work with the samples—he was too busy writing grant proposals and reports and thinking about the next step. He was talking about the importance of what we were doing, the bigger picture. It was exciting to feel a part of it.

Retired Maricopa, AZ lawyer, Susan Regan, graduated from Heidelberg in 1976. From her freshman year on, she was in the Lab every chance she had. In addition to her work there, she also served as a teaching Assistant for one of Dave’s Introductory Biology labs. She remembers him staying up all hours working to improve those labs while also keeping up with his research. Susan played a singularly important role in the life of the Water Lab that had an effect lasting long after her graduation.

Jack and Dave and family would go on canoe trips and I went along. I learned that Baker was looking for summer employees and I suggested that Ellen and Barb apply for the positions. Despite his exterior gruffness, Jack had a really big heart. I saw him mentor Ellen, convincing her to take Physical Chemistry.

I am so proud of Heidelberg College’s Water Lab for playing a central role in focusing the nation’s attention on phosphorus and on providing critical data leading to legislation [addressing Lake Erie’s nutrient pollution problems].

Becky Theller’s career led her to become Manager of Design & Editorial Services and of the Education Store at Purdue University’s Agriculture Communication unit in the College of Agriculture. She worked in the River Lab from 1974 to her graduation in 1977. Along the way she received an NSF SOS grant for a bacterial project in the Sandusk the summer after her junior year. After Heidelberg, she went on to obtain twin Master’s degrees in Horticulture and Journalism.

The River Lab was all about accuracy and honest reporting…Day-to-day we devoted ourselves to meticulous analyses and recording of data, measuring suspended solids, nitrogen, phosphorus, etc. We ran multiple, replicated tests on water samples pulled from a single spot.
When a new piece of equipment or a new test was introduced, it was carefully compared to old tried-and-true methods of analysis. Its data wasn’t included until we were sure it was true and accurate. If a point didn’t fit the curve, but the equipment was working, we assumed that point was telling us something. Data only got pitched if there was an equipment malfunction or reason to believe that we’d messed up in the lab.

Years later, when I interviewed researchers for stories as a writer at Purdue, I would use my Heidelberg research experience to follow their data and read their papers…Sometimes during an interview at Purdue, Heidelberg’s Water Quality Lab would come up in conversation—usually with a tone of awe on the part of the Purdue researchers. I’m sure some of that awe came not only from the foresight of Dave Baker in studying water quality so long ago, the longevity of the project and the volume of work done by the lab, but also from the Lab’s devotion to accuracy and honesty in science.

Heidi Martin graduated in 1980 with a double major in English and American Studies, a background that served her well in her career as a librarian with the Indiana State Library. In a classic example of a liberal arts education, the humanities major worked as a student research assistant in the River Lab for three semesters and three summers (including one summer post-graduation). She began by entering data—this was the era of key punching machines—and verifying her entries on reams of green bar printout sheets. Over time, she added analytical bench work and field sample collections to her list of responsibilities.

Working in the Lab full time in the summers, all day analyzing samples—Oh how my legs hurt! And collecting water samples in the field was heavy duty work…over fences, down slippery, rain-soaked ravines to the sampling stations and then lugging back the heavy sample containers. I remember a great chalk board on a wall of the Lab indicating the gauge stations to be sampled and work assignments for the day. We lived by that board.

These were tough times for the College; there were only 700 students during my senior year.* Baker was always writing grants; we didn’t see much of him. It was Ellen who managed the students. Tension about money was always present.

The whole time I was there, nobody knew about us; we flew under the radar. It wasn’t until 1981 that the yearbook included mention of the Lab. But there was unswerving loyalty to Dr. Baker. Everyone knew they were on a mission of sorts, even if the rest of campus didn’t know of the Lab’s existence. Ellen engendered that atmosphere of loyalty to Baker and the work of the Lab. If you didn’t share it, you didn’t last.

Mike Boehm (1987) is the Harlan Vice Chancellor for the Institute of Agriculture and Natural Resources of Nebraska-Lincoln and the Vice President for Agriculture and Natural Resources at the University of Nebraska system. He leads efforts across the University of Nebraska system for all agricultural, natural resources and related affairs and oversees the executive directors of the Rural Futures Institute, the Daugherty Global Water for Food Institute and the Dean of the Nebraska College of Technical Agriculture at Curtis. Mike’s purview covers

*As one of many cost-saving efforts during this period, the College had determined to eliminate its Historic Preservation Office. Heidi voluntarily took on the task of curating the collection. Eventually those documents formed the core base of the Heidelberg Archives, which proved an invaluable resource in researching the roots of the NCWQR.
an enterprise consisting of over 1,600 full-time employees, 330 tenure track faculty, 40,000 acres of land and annual expenditures in excess of $215 million. It’s a fairly responsible position.

In 1985 Boehm began an independent year-and-a-half research project with Ken Krieger that wrapped around his year’s duty in the Army Reserve. One of Mike’s projects involved conducting a survey of farmers’ field tillage practices (conventional, no-till, reduced-till) while driving county roads in a ‘72 VW bus. Learning about cropping systems was a seminal experience for the future career of the young man who grew up in a suburb of Cleveland. He also worked with Jack and Ellen on a study of sediment loading of pesticides after storm events (among other projects).

I rely and often think about my time at the Lab; it informs how I work with people in addressing the linkages between agriculture and resilient natural resources stewardship.

My experiences in the Lab had a profound impact on my professional life. It was my first exposure to a laboratory environment and to high-end scientific research. The WQL was such a supportive place to work. I learned about collaborative work with Ken, Jack and Ellen; we got a lot of work done, but it was fun. On the fourth of July, Mrs. Baker brought in an angel food cake with blueberries, strawberries and whipped cream.

In my graduate program at the Ohio State University, people noticed that I came out of the undergraduate program at Heidelberg.

*Sara Creque-Thomas* began working in the Water Lab the summer after her freshman year, continuing until graduating in 1999. At this writing she is the Lake Erie Unit Manager for the Michigan Department of Natural Resources, Fisheries Division. She worked primarily in the Lab’s chemical analyses area.

The WQL was the main reason I came to Heidelberg, having learned of it through a high school science project. The real-world work experience I gained there played a big part in my acceptance into my graduate program in Michigan.

I remember countless hours of washing glassware. I’d set my notebooks up as I worked and study for exams. Now [since moving from the basement of Bareis Hall] they have windows!

I am proud to say that I am a Heidelberg graduate and that I had worked in the WQL.

After having earned an MS from the University of Illinois at Urbana-Champaign, *Seth Hotham* (2000) became one of a number of Heidelberg graduates that have found employment with the Northeast Ohio Regional Sewer District in Cleveland where he is currently Supervisor of Environmental Assessment.

I worked the summers of 1999 and 2000 in the WQL, collecting samples from the field and performing analyses in the lab—but chiefly washing glassware. I really enjoyed the family feel within the Lab, but I also learned a lot, especially about following up on responsibilities.

The watershed studies in which I took part while at the Lab are highly relevant to the work I do today.

Like Seth, *Beth Toot-Levy* (2001) began her professional career with the Northeast Ohio Regional Sewer District. After 14 years she took a position with a private consulting firm,
Geosyntec, where she is a Project Scientist working primarily with municipalities and agricultural communities on Clean Water Act initiatives.

When I came to Heidelberg, I didn’t know anything about the Water Quality Lab. I thought I would probably become a teacher, but that soon changed, and I switched my major from Education to Water Resources.

I worked on the Biology side with Dr. Krieger as one of his “bug pickers” on an Army Corp project sampling benthic invertebrates in Toledo Harbor, before and after dredging operations. I also worked on Krieger’s Mayfly Watch project and analyzed the contents of fish stomachs for possible consumption of zebra mussels. I remember Ken, while wandering about the Lab, would leave his coffee cup everywhere. Eventually he’d come back to find it and drink it cold.

I was clueless about professional options when NEORSD called Krieger about a job prospect. After working there for several years, I came to realize how well-prepared Heidelberg and my work in the WQL had made me for my career.

Justin Harris and Ron Maichle (2004) were something of a bug-picking team, working for two years, during academic semesters and summers, in Krieger’s lab. Justin worked exclusively on the biology side of the NCWQR while Ron also spent a summer in the Chemistry side. Maichle also spent one summer on a fish ecology internship working with Sara Creque who at that time was employed by the Illinois Natural History Survey. After several jobs working as an environmental chemist, and eleven years working for First Energy, Ohio, Justin took a position as an environmental engineer with Florida’s Municipal Power Agency. Ron is a Senior Investigator with the Northeast Ohio Regional Sewer District

Justin: With experience we got better and better at taxonomic identification, sometimes getting our critters right down to genera. It was a great group of people to work with, everyone cared and it was one of the highest paying student jobs on campus. Ron and I were able to slowly chip away at Dr. Krieger and eventually got to listen to music while working.

One of the best things I got out of my time in the Lab was exposure to technical writing. Ron and I co-authored a report with Dr. Krieger on a method for sampling mayflies. That was my first experience in professional writing, which became an important part of my career as I now handle all environmental compliance issues for my company’s multiple power plants.

Ron: One of my fondest memories occurred during my senior year as the Lab was moving from the basement of Bareis to the top of Gillmor Hall and crews were just beginning renovations to our old laboratory spaces. I got to put a sledge hammer to one of the walls; very satisfying.

More to the point, fresh out of college I found I had more real-world practical work experience than most other newly-employed biologists from other institutions. I still talk with researchers in my field that I first networked with during my Heidelberg days.

Natalie (Johnson) Pirvu is an administrator for two ODNR Divisions—Natural Areas and Preserves, and Parks and Watercraft. She graduated in 2005 after having worked some in the Chemistry section, but mostly on various macroinvertebrate projects with Krieger. She was lead author with him in preparing the Old Woman Creek Atlas of Chironomid midges.4
I had an experience few other people have had. For one thing, I have acid boiled a LOT of midge head capsules. I learned so much from Dr. Krieger, seeing how excited he was to be out in the field and collecting as well as in the lab working on his samples. People have an automatic, positive response when told I am a product of Heidelberg’s NCWQR.

My work in the Lab absolutely impacted my career. Heidelberg was contracted to look at macroinvertebrate communities in the Sandusky before and after the removal of St. John’s dam. That was where I first got to know some of the ODNR and OEPA people I now work with. As an ODNR coordinator reporting on hazardous algal blooms in Lake Erie, I rely on my exposure to laboratory analyses to help me explain the science behind policy decisions being made. I love my work as a public servant; I feel like I am making a positive difference.

Jim Ryan (2008) spent one year working with Ken Krieger on macroinvertebrates and three years working on the chemistry side with lab technicians Ellen Ewing, Barb Merryfield and Jack Kramer. His favorite part of the job was working with his hands—and annoying Ellen. After graduation he worked for a while as an environmental educator before changing careers to become a licensed electrician.

Although I didn’t choose to stay in the environmental field, I will remember my time in the Water Lab as some of the best years of my life. I still consider the people there almost as family. While washing glassware, preparing materials for testing, conducting analyses of total phosphorus and nitrogen and suspended solids, I still found time to tease Ellen. It was a hobby to pick at her just to get her going. I remember changing the color caps on a set of Sharpies she regularly used. She used the word, “annoying” with me a lot.

Kristie (Thomas) Boulee graduated with a Water Resources major in 2009. Typical of many other student research assistants, she put in 10 hours/week in the Lab during the fall and spring semesters and worked full time in the summers (2007-2008). During the academic year she worked with the chemists and during the summers with the biologists. For four years after graduating she worked as a chemist for Bunge Company’s soybean processing plant in Bellevue, OH before opting for a more challenging career as a stay-at-home Mom.

After paying your dues washing glassware and, after enough experience, demonstrating competence with the lab equipment, Ellen showed her trust in you by allowing you to perform chemical analyses unsupervised.

On the biology side, I worked with Chris Boehler on Krieger’s hypoxia study in Lake Erie’s central basin, sometimes going out on the boat to collect samples. I also worked with Gary Winston and his student assistant Ben Laubender on their study of oxidative stress in mayflies. The importance of the research aside, it was working with these people that made the experience so enjoyable.

Matt Lamoreaux also graduated in 2009. After a series of positions working for various environmental consulting firms on air and water pollution issues, he eventually landed a dream job with the Ohio EPA in the Division of Surface Water overseeing Clean Water Act Section 401 stream and wetland permitting.

Those four semesters working in the Lab’s Chemistry section got my career on track. My experience conducting analyses of total suspended solids, conductivity, TKN, total phosphorus
and, of course, plenty of glassware washing, gave me an appreciation of everything that goes into water quality analyses. It made my career possible.

\textbf{Ben Laubender} (2010) carries two business cards. With the 108\textsuperscript{th} Air National Guard he is a Bio-environmental engineer whose job is something of a hybrid between that of a teacher, environmentalist and engineer. His Monday-Friday job is as an Industrial Hygienist with Toledo Refining Company where he looks after employee health and safety.

In the spring semester of 2008 and for the following two summers, I worked with Gary Winston on the ability of mayflies in the genus \textit{Hexagenia} to resist pollution-based oxidative stress from free radicals. That work led to my first professional publication.\textsuperscript{5} I really enjoyed learning graduate-level toxicology from Gary. Initially I was overwhelmed but it eventually came together like the pieces of a jigsaw puzzle.

My work in the NCWQR absolutely impacted my career. I came in as a student and came out as a researcher. There was so much going on in the Lab. I was told in high school, “You’re not college material; you should look for something else.”* Heidelberg changed my view of myself.

\textbf{Tamara Keller} passed away in December of 2010. A returning adult student with a family, Tammy was only able to take a few classes each semester. Her interests in biology and environmental topics, however, led her to explore the possibility of doing some work with Krieger. Beginning her studies in Ken’s lab in 2006, she became one of his strongest macroinvertebrate research assistants, serving as lead author on the Mayfly larvae and Caddisfly larvae taxonomic Atlases and second author on the Cladoceran Atlas. Jake Boehler remembers her as a kind, level-headed person who helped him master some of the more challenging details involved in identifying macroinvertebrates. Even when her cancer came out of remission and working in the Lab became more challenging, her commitment was such that she nonetheless kept to her microscope for as long as she could.

\textbf{Chemistry major Barbara (Purviance) Reitenbach} graduated in December 2011 and immediately started work as a bench chemist at POET Biorefining in Fostoria, OH. Within a year she was promoted to Quality Manager overseeing all testing, including water testing, within the facility.

I pestered Ellen for a work-study job in the Lab until she finally hired me. Although I worked in both sides of the NCWQR, most of my time was spent on the chemistry side. I loved it. That lab has such a warm, special place in my heart. It’s like a little family up there. I really respect their passion for what they do. Such a great opportunity for Heidelberg’s students.

I still remember where I was standing when Ellen said, “You must meet Susie Daniel; you’ll love her.”* She became a life-long friend.

\textbf{Susie Daniel} (2013) is a Senior Research Support Specialist in the Great Lakes Center at SUNY, Buffalo State. Her research focuses on the ecology, taxonomy and monitoring of benthic invertebrates in the Great Lakes. As part of her duties working with the Great Lakes Long-term

\textsuperscript{*More or less believing what he’d been told, Ben went into the Navy after graduating. After the service, and despite his high school counselor’s advice, he thought he’d give college a try.}

\textsuperscript{†Ellen doesn’t miss much.
Biological Monitoring Program, she collects invertebrate samples while sailing aboard the EPA R/V Lake Guardian, which she then counts and identifies.

I worked in the Water Lab from 2010-13, including two summers as a full-time lab technician. In the chemistry side I collected samples, performed analyses of suspended solids, TKN and conductivity and washed glassware. About that last part…To this day I still have students working in our lab follow Ellen’s Rule: Rinse out vials with deionized water three times.

I first learned my macroinvertebrates working with Krieger on an OEPA river study of crustaceans, insects and chironomids. I loved working with everyone there; it’s such a healthy work environment. My favorite times were sitting with Dr. Krieger arguing over the identification of some species. I won maybe 50% of the time.

One day Krieger got an email from a Heidelberg graduate who had been working at Buffalo State that the Center was looking for a macroinvertebrate technician. I started the day after graduation.

Oh, and Dave Baker is the Steve Jobs of the environmental world.

*Judy Smith:* At this writing, Judy, a junior Environmental Science and Math double major, is a student research assistant to Rem Confesor working on several of his watershed modeling projects. As a freshman, Smith went on a trip with Heidelberg’s Chemistry Club for a tour of Oak Ridge National Laboratory in Tennessee. The experience introduced her to the application of computer science and mathematics to modeling complex systems, which in turn led her to apply for—and receive—an REU at North Carolina A&T State University for that summer. The experience provided Judy with her first taste of working with watershed models. Ironically, it wasn’t until she returned to Heidelberg for her sophomore year that she learned that NCWQR’s Rem Confesor is widely known for his watershed modeling work. Rem was delighted to invite her to work with him; she was his first student assistant who did not require a lengthy introduction to the tools and procedures involved in watershed modeling.

At present, Rem has me working a bit with SWAT and lot more with NTT,* but my favorite thing is working on his climate change project. The goal of that study is to downscale the Global Climate Change model to the Maumee watershed which, after bias correction for missing data, can be plugged into SWAT to predict the effect of climate change over the next sixty years on nutrient export from the Maumee River into Lake Erie. I am working with Dr. Confesor on preparing a paper for possible presentation at the upcoming IAGLR† meetings.

After Heidelberg, I plan to attend a graduate program leading to a Ph.D. in watershed modeling, with emphasis on agriculture. Obviously, my experience working in the NCWQR with Rem has played a big part in my thinking about a future career. Rem is remarkable to work with. When I go to conferences and mention to another researcher that I’ve been working with him at Heidelberg, a light goes on in their eyes. Suddenly I’m on equal footing with them, talking about the details of each other’s work.‡

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*The Nutrient Tracking Tool (NTT) is a modeling tool used to estimate nutrient and sediment losses from agricultural lands that was developed by the Texas Institute for Applied Environmental Research at Tarleton State University. Rem Confesor is the NTT expert in the Great Lakes Basin.
†The International Association of Great Lakes Research (IAGLR) is one of the principal scientific organizations devoted to research on the Laurentian Great Lakes and its watersheds.
‡Judy presented some of her work with Rem at the 2019 IAGLR conference. Reports are that not only was her talk well received but it “blew her audience away” to learn this modeler was a Heidelberg undergraduate.
Many comments on the Water Lab by staff members have been worked into earlier chapters. Here, miscellaneous thoughts of past and current staff members that didn’t seem to fit in elsewhere are offered, beginning with those present from the Lab’s earliest days.

Peg Baker: Ellen Ewing, in responding to a question about unique features of the Water Lab that enabled it to develop into a nationally renowned research facility, referred to Dave’s wife, Peg. “She has been as much a part of the Lab as any of the rest of us. She made Baker possible.” Here’s Peg:

I provided balance, the steady family life Dave needed. My job has been to occasionally pull him back from overworking himself, but most of the time to just get out of the way. In a way, though, the work has not been that hard for him; it’s who he is. His nickname is Data Dave; along with fishing, canoeing, hiking and singing, data analysis is actually part of his recreation. Making accurate, low cost data available to modelers and decision makers is his passion. That passion for the work is part of the glue that holds the Lab together—that and the very competent and loyal staff.

Dave’s parents were very supportive, hard-working survivors of the Depression. In high school, where his mom was a teacher, Dave had inspiring coaches and an especially influential biology teacher, Franklin Smith. Although he came to Heidelberg headed for the ministry, Dave got bitten again by the Bio-bug in Dr. McQuate’s and other classes and changed his major. When Dr. Mac retired, not only his job but also his house along the Sandusky River was available. In 1967, the “McQuate Estate” became the “Baker Acre.” We are so grateful that Dave could make his career at Heidelberg and we could raise our three kids, Sarah, Mark and Susan, at the house on Riverside Drive where McQuate’s daffodils still come up every spring.

In a real sense, the whole Baker household was involved in the river studies of the early 1970s. The term “event” had a special meaning—a storm runoff event on a weekend meant a family drive to several bridges over the Sandusky River where the kids would help pull up buckets of water for sample analyses the next week.

Dave feels it is very important to communicate the Lab’s data and interpretations of those data to as wide an audience as possible. That’s why he gave so many talks over the years. I usually edited his papers (English teachers are good at that) and listened to his talks. Sometimes he would shoot over my head. When I asked for clarification, he was patient but also wary of oversimplifying complex issues. In return, he helped me when I directed plays at Old Fort High School and when I had lines to learn for the Ritz Players productions. He even took small roles in a few of them. His recent escape-run across the stage in Arsenic and Old Lace will long be remembered with a chuckle.

And today, Dave still writes and edits papers for publication. When I nag about too much work, he simply replies, “What else would I do?” He loves his work and the people who make it possible. … I just want to add that Dave is the most patient, honest, hardest-working and supportive person I know.

Dave Baker: Dave attributes the long-term success of the Lab to a combination of fortuitous circumstances, careful planning and hard work. One of Dave’s early disappointments, however, was that his growing involvement in research drew him increasingly away from the
classroom. “I loved teaching General Biology. Originally, the fall semester course had both majors and non-majors and I enjoyed the challenge of working with both groups.” With regard to his secret recipe for building the Lab, Dave has said:

In many instances we were in the right place at the right time with the right people. For example, (a.) We were located virtually on top of the Sandusky River, one of the main tributaries to Lake Erie in the late 1960s at a time the Lake was being called “dead;” (b.) The Biology Department gave us the green light [and Administration the money] to institute a three-week river studies component to my Introductory Biology course, which (c.) subsequently gave me the data to obtain a grant for our first major study, a project investigating low-water conditions in the river during mid-summer, that (d.) was upset by the wettest summer in decades, leading to (e.) our first important discovery, a new understanding of the significance of storm events in nutrient transport.

And there’s our incredible staff. Jack, to pick just one example, was central to our early and continued successes. He could easily be the prototype “Jack-of-all-trades.” He breaks the mold however, because he is also a “master-of-all-trades.” OK...that’s an exaggeration. Let’s put it this way, Jack has a working knowledge of diverse “trades”…and the skills to implement that knowledge.

Another of the chief factors in the Lab’s growing reputation was our strict attention to quality control, which has been a central facet of our operations right from the start. Interestingly, I never had a statistics course, but a lot of my appreciation for quality control came from my Ph.D. advisor at Michigan, Dr. Peter Ray.

The future quality of life in this area will depend on how well we use the land to produce the food, fiber and energy we need while at the same time minimizing [negative] effects on water resources. The Lab has some unique insights and data sets pertaining to these issues and I hope for a solid future for the Lab, moving ahead.

**Jack Kramer:** Jack’s family ran a greenhouse near Cleveland where he first became interested in the effects of fertilizers on plant growth. He came to Heidelberg in 1966 as a sophomore majoring in Chemistry. The following year he started working for Baker as a T.A., Lab prep person and technician helping to set up and run the River Studies labs Dave was developing for his Introductory Biology course. As noted in the first chapter, after graduating he became the Lab’s first full-time employee when Dave received his grant for the Flow Augmentation study. Over the years, Jack became famous for his dyslexia, which made for any number of entertaining messages being passed around the Lab.

In my job, you needed to know a little about everything.

Professors Ed Ashworth (Geology), Ray Wise (Physics) and John Jakobs (Computer Center) were brought on to help with the Augmentation project in the summer of 1969. None of them knew anything about the instruments or the biological analyses we were to perform. I had my hands full. Even the biologists knew little about standard chemical analyses.

Because I was managing a lab without even a Master’s level degree, I periodically experienced issues being respected by certain researchers outside of Heidelberg. However, by the mid-1970s I was invited to serve on an advisory board to the International Joint Commission considering quality control in nutrient analyses. We had become one of only six labs with the ability to detect low levels of phosphorus.
By the early 1980s, the Lab was already well past the OEPA, USEPA and USGS in our data handling methods. We were very early in digitizing the data coming out of our analytic instruments. Computer students Rich Leslie and Greg Yarmoluk helped me set up our data entry systems so that data could flow directly from analytical machines to computer storage files, greatly reducing human errors associated with hand entry of data.

The staff was a family, making the WQL a great place to work. I was given a lot of freedom to move in new directions when I saw opportunities to do so.

Ellen Ewing and Barb Merryfield: Ellen and Barb, having worked side-by-side in the chemistry section for so many years (Ellen began in 1976, Barb two years later), chose to be interviewed together. Although Ellen spoke more often, it was clear that she voiced their mutual perspective.

Dave Baker is a novel thinker; he never thought anything was impossible. His training as a plant physiologist was in nutrient transport systems in plants. So why not apply similar thinking to the transport of nutrients in river systems? Baker was a dreamer, he could see five years ahead. And then Jack would find, jury-rig or invent the technology to make it happen, we’d crank out the analyses and Pete would find a way to crunch the data and identify trends.

The automated Lab Information Management System Jack invented and put into effect was a marvel created far in advance of anything being used in other research labs. It was a big part of the reason we were able to generate and analyze the quantity of data we did with such a small staff.

I remember watching Baker run through a practice presentation to the staff for a particularly important talk he was going to give. In seeking our feedback on the clarity of his presentation, he said something that I think highlights a lot of what motivates his work and the need he feels to communicate the Lab’s results: “I just want people to believe this is the most honest assessment of the data I can make at this time.”

The 1990s were a lean time for us; we went a long time without pay raises. And yet, somehow Baker found the resources to keep the us together. We relied then, as we still do today, on our undergraduate student research assistants to get the work done.

Although we’ve been here the whole time, it’s important to remember other full-time staff members who worked with us for a significant number of years before moving on, people like Mary Dobstaff (1977-82), Francine Turose (1978-86) and Laura Wallrabenstein (1987-95).

M. Patricia Hillmer and June Huss: Dave Baker is generally shy of speaking too warmly of his own accomplishments—with one exception. He does swell his chest a bit over the role he played in keeping Pat Hillmer in Tiffin. In the 1970s, Pat’s husband Max taught Psychology at Heidelberg and she got to know Peg through the Faculty Wives Club. The two couples soon became fast friends. Pat graduated from Heidelberg in 1976 with a major in English and continued her education with a Master’s in Library Science from the University of Michigan.* At that time there was a scarcity of jobs for librarians with advanced degrees and she searched widely for a position without success. As Pat remembers it, one day Dave

*Speaking of paladins for a noble cause, Max resigned from teaching to take care of the house and their two daughters, Felicity and Jennifer, while Pat attended graduate school.
called with a proposal: “I’ve got something to suggest; how would you like to be the administrative assistant for the WQL?”

This was around the time when the Lab was gearing up for the Lake Erie Nearshore project with a budget over $600,000. The WQL was in the process of hiring a dozen new researchers, its long-term tributary studies were still underway and there were reports to be filed and new grants to be prepared for submission. Dave was swamped and really did require administrative assistance, so Pat took the position. She had been working at the Lab for about a year* when the Head Reference Librarian position opened up at the Tiffin-Seneca Public Library. Hillmer would eventually serve many years as the Library’s Director, a member of the Tiffin City School Board and a central figure in the cultural life of the community—for all of which, Dave Baker has been pleased to take full credit.†

Not long after Pat’s departure, June Huss began working part time as Dave’s administrative aid. In a curious twist, her other part time position was working for the Director of the Tiffin-Seneca Public Library. When, some few years later, Pat Hillmer became the Library’s Director, June left the Lab to become Pat’s full-time administrative assistant, a position she held for the remainder of her working career. Pat remembers June as a strong-willed “rule-the-roost sort of personality, but someone who really knew the business part of the Library.” The same was true for her work with the Water Lab. Analytical chemist, Josie Setzler, shared office space with June for several years.

This was a time, in the early 1980s, when computers were just coming into prominent use in our daily work. Both of us were trying to teach ourselves how to make the shift [from typewriters] to the earliest word processors with floppy discs and all that. It was cumbersome and difficult to master, but it all felt so state-of-the-art at the time. June was highly organized and efficient in her work; we got along well.

Bayliss (Rock) Prater: At a remove of 40 years it’s difficult to sort out, from interviews with various WQL staff members from the period, the source of the personnel problems that wrecked the Lab from 1978-79. On the one hand, it was a time when the Lab seemed to have hit a high point in its operations—an EPA grant of over $633,000 to fund the WQL’s part of the two-year EPA-sponsored Lake Erie Intensive Study (the Nearshore project), a full-time staff of 18, and the R/V Roger R. Simons flying Heidelberg’s flag. And yet, as discussed in Chapter Two, negativity on board the Simons and in the Lab at Heidelberg required Administrative intervention on several occasions.

Rock Prater, Associate Director of the Lab (1976-79), is a person of enormous energy and charisma; his is a personality that seems to either attract or repel others, with little neutral ground in between. In his days working on Lake Michigan through the Chicago USEPA office, Prater had developed close friendships and working relationships with a number of administrators and biologists, a fact that played an important role in the EPA’s asking Heidelberg

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* In December of 1978, the Kilikilik (Heidelberg’s student newspaper) published Hillmer’s “WQL Measures Ten Years of Growth,” a detailed overview of the Lab’s first decade that provided many useful insights into that critical time period for the preparation of this history. †

† Or so he has claimed.
to submit a proposal for the upcoming Nearshore Study. On Rock’s recommendation, the WQL hired a number of those biologists for the Nearshore study.

But Prater (and some of the biologists he brought on staff) also triggered inimical reactions on the part of the WQL’s chemistry lab technicians. The details of the various disputes are not as important as the impact on the work atmosphere within the Lab. It was toxic. According to Prater:

The problems stemmed from a clash of two different cultures. The biologists were mariners, the chemists were not. The shipboard is a whole different world.

Though undoubtedly true, each group’s disparaging comments about the other’s behavior suggests a deeper rift than a simple dispute over different styles of deporting oneself. When Rock left Heidelberg before the second summer of work got underway, many on the biology crew felt their boss had been fired and left the Lab shortly after completing their assigned tasks. It seems that Dave Baker’s many skills as the Lab’s founder and Director, were not well suited to managing the divisiveness within the Lab during the Prater era. That said, the Nearshore study was completed on time, within budget and with a very high degree of professional competency.

Ken Krieger: Although Ken was one of the biologists who Prater hired in 1978 for the Lake Erie Nearshore study, he had not known Rock prior to applying for the job. When Rock left Heidelberg to start up his environmental consulting firm, Aqua Tech, most of the other biologists went with him. For several years, phycologist Phil Kline continued with the Lab,* but when he too departed in the early 1980s, that left Krieger as the Lab’s only Ph.D. biologist. Here’s Ken speaking about his situation as a biologist among the chemists and, later on, in his role as the Lab’s Director:

The primary focus of the Water Lab has always been the chemistry of nutrient loading, with biology sort of an interesting appendage. In fact, some of the WQL’s critics have referred to it, somewhat disparagingly, as “the Phosphorus Lab” because of its long-standing emphases on the transport of that nutrient within aquatic systems. But during my entire time here, I’ve always been encouraged to follow wherever my research interests may have led.

I became the Lab’s Interim Director in April 2010 after Gary Winston’s resignation. In July, the State of Ohio withdrew its line item funding for the Lab and, at the same time, the Board of Trustees began to look for ways to monetize the Lab through possible licensing and patenting of our methods. It was a busy first couple of years on the job.

Several of my proudest accomplishments were, with Dave and Pete, helping to diversify our funding resources, reinstating State funding in 2012 and reintroducing the practice of preparing the Director’s Annual Report.

The Advisory Committee of outside researchers, government and industry representatives I put together, however, didn’t quite work out as I had hoped. Although it proved useful as a means for

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*In addition to carrying on his own research, Phil co-taught an Aquatic Biology course with Ken.
communicating what was going on in the Lab to these important folks…my expectation the group would offer ideas for new directions for the Lab never really materialized.

Much more of a disappointment was Administration’s decision to cut back the University’s Environmental Science program, ending the Water Resources major and eliminating the Limnology and Aquatic Biology courses I had long taught.

_Pete Richards_: It would be difficult to find a better example (and advocate) of the value of a Liberal Arts education than R. Peter Richards. Before answering the WQL’s advertisement for a chemical limnologist to join the Lake Erie Nearshore Project in 1978, Pete had acquired twin undergraduate degrees in German and Geology from Oberlin College and a Ph.D. in Geology from the University of Chicago emphasizing paleoecology. His only chemical limnology background came, after seven years of teaching Geology at Oberlin, from an aquatic ecology Post Doc at the University of Michigan.

When I interviewed with Dave Baker and Rock Prater, I was upfront in saying I was not a limnologist. But I told them, “If you’re looking for a numbers guy, I can do that” and they hired me. I set about helping the chemists find patterns in their data and found I had a talent for discovering trends in numbers.

Before coming to Heidelberg I had taken one biostatistics course in graduate school and had exactly one hour of training on a computer while at Oberlin. I had to teach myself computers, programming and advanced statistics, all for the goal of turning reams of data into useful information. Jack and I developed the Lab’s data management system from the ground up. He developed the programs to integrate the analytical chemistry equipment with our data storage systems and I came up with the descriptive statistics programs to find patterns in the data.

When it became clear in 1999 that Dave’s health would not permit him to continue as Director, the most logical option for the Lab seemed for me to succeed him, at least temporarily. It was a struggle for me as I tend to view myself more as an active follower than someone given to planning and looking to the future. I was OK handling the financial books and acting as the “face of the lab,” but following up on the abundance of complex tasks that had to be addressed was very stressful.

From my early work developing programs exploring our nutrient loading data, I eventually evolved my own set of research directions. When Ken assumed the Directorship, I finally had the support and time to begin moving the Lab towards modeling, eventually developing a network of outside colleagues as part of a multi-university consortium of modelers.

From his decades of work with the Lab’s data, Pete has developed a nuanced perspective on how that data came to be and why it has proven so valuable.

There’s a serendipitous, almost accidental aspect to the way our data sets have become so important to the larger research community beyond Heidelberg. From an experimental design standpoint, we really couldn’t justify the mass and extent of data we were collecting. Statistical models would’ve suggested at least 25% less sampling to adequately address the questions we were asking at the time. In large part, we collected as much data as we did because Dave just liked data. Ultimately, however, the richness of our data is what has made it so useful for so many uses beyond those for which we had originally designed our studies. It’s not uncommon, today, for modelers and other researchers to talk about “the Heidelberg Data” when checking the utility of a predictive model, as in “Well, let’s see what the Heidelberg Data says.”
Josie Setzler: Josie was hired in 1979 to spend half her time working in the WQL and the other half teaching in the Chemistry Department. This was the period when the Lab obtained its first gas chromatograph and one of her first jobs was to get the system functioning for pesticide analyses. In 1981, she dropped her WQL duties, remaining half-time teaching a few Chemistry courses. In 1997, after receiving her Ph.D. from the University of Toledo, she returned to working full-time in the Lab (though still teaching a few Chemistry and Water Resources courses, as time allowed). Along with quality control duties, one of her chief responsibilities was maintaining the Lab’s Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) device for measuring metals in water samples. In 2006, she left Heidelberg to devote her energies to humanitarian activism.

I came at the end of the Roger R. Simons period when the Nearshore project was finishing up and people were moving on. It was a turbulent but exciting time in the Lab as I got to work with new, state-of-the-art technology and learn about quality control.

I know Jack and Ellen had some problems with Tim Loftus, but I got along well with him. He was looking for new opportunities for the Lab and spent a lot of time researching what would be the best ICP system for us to purchase and securing funds to do so. He also worked hard to disseminate information to those outside the Lab who would find it useful.

I was proud that my dual roles in the Water Lab and the Chemistry Department helped form bridges between the WQL and the educational mission of the University.

Nancy Miller: Nancy was initially employed in 1986 as an invertebrate-sorting assistant to Ken Krieger. The well-testing program, however, also started that year and she was soon charged with keeping track of the program; as of 2017, she has been the person who has worked with the public in orchestrating the Lab’s collection, analysis and reporting on some 70,000 well samples. As various staff members left Heidelberg over the years—June Huss, Laura Wallrabenstein, Josie Setzler, Anne Stearns—she has also picked up various pieces of their responsibilities. Nancy also served as the Lab’s social chairperson; she was the chief organizer for the annual fall potlucks and the holiday White Elephant Gift Exchange party. With over thirty years of experience and having worked with each of the Lab’s Directors as the NCWQR’s Business Manager, Miller’s insights into the its administrative inner workings nicely complements the perspectives of Kramer, Ewing and Merryfield on the analytical lab.

The existence and constancy of this Lab over the years would not have happened were it not for Dave Baker. Everything here, from the big machines to the paper clips exists because of D.B. He never micromanaged; he just told you what he wanted and left you alone to do it. And Dave’s love for Heidelberg is unmatched, a fact which kept the Lab here during the rough times of the 1980s and 1990s.

The sense of family spoken of by many people who have worked here stems from both Dave and Peg. She has played an essential role in the Lab’s history. She has provided Baker with the emotional support and time he needed to develop the lab. And of course her role in bringing Dave back to health after being diagnosed with cancer was crucial.

I would divide the history of the Water Lab into two sections: Pre- and Post-1999, the year of Baker’s [first] retirement. Until then, the focus and identity of the Lab under Dave’s leadership
was clear and consistent. Although Pete Richards maintained that focus, we all knew the Lab was about to experience a lot of change when a new Director would come in from outside. That of course did occur, and Baker and Krieger deserve a lot of credit for keeping things going—Dave for coming out of retirement to calm things down after Loftus departed and Ken for giving up most of his research to take on the Director’s duties after Winston left. Krieger, did an outstanding job; he has a gift for details and never let anything fall through the cracks.

Laura Wallrabenstein: Laura worked as the Lab’s Quality Assurance Coordinator from 1987-95. Initially hired to ensure reliability of the nutrient and pesticide tributary loading runs and nitrates from the well-testing program, she soon found herself preparing slides for talks Baker, Pete—and eventually herself—were increasingly being asked to present. After leaving Heidelberg, Wallrabenstein spent several years as a quality control technician at Aqua Tech until the company was purchased by Alloway Environmental Testing and the Melmore facility was closed. Since then, Wallrabenstein has worked with the Seneca County General Health District where, at this writing, she serves as Director of the Environmental Health Division.

We were early adopters of Mac computers and laser printers; it was all new to me and I had to scramble to keep up. Dave and Pete were always needing slides to be added to their presentations at the last minute, which required me to make a run to the Kodak plant in Findlay for overnight development.

The work was great, the people were wonderful; it was fun to have a job you looked forward to waking up to in the morning. The communication skills I developed in giving talks before general audiences on behalf of the Lab has certainly served me well in my job today.

Tim Loftus: Tim was the first person from outside Heidelberg to assume the position of Director of the NCWQR. After his three years at Heidelberg (August 2002-July 2005), he worked for ten years as a water resource planner with the Chicago Metropolitan Agency for Planning after which he assumed the Meadows Endowed Chair in Water Conservation in the Department of Geography at Texas State University, San Marcos where he became Chief Conservation Officer and Professor of Practice in Geography.

I was attracted to the position at Heidelberg by the Mission of the Lab and the opportunity to assume a leadership position in its important work. Among the most important accomplishments during my Directorship, I would count my development of a three-year Strategic Plan, being at the helm during the move from the basement of Bareis to the new spaces at the top of Gillmor Hall and placing the Lab on a more secure financial footing than when I arrived.

I am aware that some of the staff complained about various decisions I made and there was hurtfulness on both sides of those issues. I don’t know how much, if at all, that played into Administration’s decision to not renew my contract. In any case, I was not expecting to be let go when Vice President for Academic Affairs Laura deAbruna called me into her office to say they “wanted to move the Lab in a new direction.” I do think it likely that I misplayed the politics of my situation with the Board of Trustees by not being accommodating enough to some of their ideas about what I should be doing as Director.

I will say that although losing my position at Heidelberg was a painful experience, it ultimately proved most beneficial for my subsequent career. I am grateful for the opportunity to have worked at the Lab and extend my best wishes to everyone there.
Aaron Roerdink: Aaron joined the NCWQR in 2006 on a one-year contract stipulating that 2/3 of his responsibilities would be with the Lab and the other 1/3 would be teaching in the Chemistry Department. In 2012, Administration converted his status to a tenure track position. Although he still holds a dual appointment, as Chair of the Department of Chemistry and Biochemistry, his ability to work in the Lab is limited during the academic year. After receiving his BS from Central College in Pella, Iowa and a Ph.D. from the University of Wisconsin-Milwaukee, Roerdink worked for several years in the highly regulated pharmaceutical industry before coming to Heidelberg. It was originally thought that he might replace Jack Kramer on his retirement but over time his work in the Lab has evolved more towards quality control.

For many years the Lab had done well by basing its quality control programs on proficiency testing. However around the time of my arrival the State had implemented its Credible Data Program and my first several years focused on helping the Lab get in synch with the CDP.

Before me, Anne Stearns had maintained quality control and final data screening prior to its release on the web. When she left in 2008, among other duties I took over her quarterly reviews of our data.

The Lab’s greatest strength has clearly been its personnel. David Baker is the most selfless researcher I’ve ever run into. For Dave, it’s not about making a bigger name for himself but to do work that will make the world a better place. And in the Lab’s day-to-day grind, Jack, Ellen, Barb and Nancy have always found ways to get the work done, in spite of all the mechanical and other problems that get in the way. An important part of the equation has long been including our undergraduates in the Lab’s operation.

Although the Water Lab is situated within a small Liberal Arts institution, the work it churns out is of the caliber of an R-1 research facility* and it has attracted researchers like Dave, Pete, Rem and Laura, who could have excelled in such an environment. R-1 institutions have developed clearly defined objectives for researchers interested in advancing their careers with recognized milestones along the way in moving from one rank and pay scale to the next. But what are the milestones for researchers here at Heidelberg? What are the criteria—how many publications, presentations, editorial duties, etc.—for attaining Senior Scientist status? As the old guard, the founders of the Lab, are replaced by researchers from other institutions, it seems this is a question that merits consideration.

John Crumrine: Although John’s contacts with Dave Baker and the Water Lab stretch back to the early 1970s—growing up in Tiffin, he had attended Heidelberg for two years and his wife had graduated from the school—he didn’t join the team, full-time, until 2007. Crumrine’s early career as a hydrologist for the U.S. Forest Service required him to move his family to a different part of the country every few years. In 1978 he took a position as a watershed management technician with the Seneca County Soil and Water District based in Tiffin. In the late 1980s, he shifted to the U.S. Soil Conservation Service† (also in Tiffin) where he remained until retiring in 2003. After a few years of working in recycling and for the County Engineer’s office, John took a

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*The Carnegie Classification of Institutions of Higher Education categorizes all accredited colleges and universities in the U.S. by their educational and research characteristics. Doctorate-granting universities are classified as R1 (very high research activity), R2 (high research activity) or R3 (professional) universities.
†Now the Natural Resources Conservation Service.
part-time job with the NCWQR as its Agricultural Projects Coordinator. From 2007-10, he served as the Lab’s environmental extension person, helping local agencies and farmers make sense of the Lab’s data and insights and working with them in developing Best Management Plans (BMPs) for area farms. In 2011, Baker convinced John to come out of retirement for a brief spell to help the Lab develop an online BMP Toolkit to help farmers manage dissolved phosphorus runoff from their land. The toolkit has since been widely distributed.

The agricultural community did not always appreciate or fully understand the Lab’s work and data. Sometimes they didn’t agree with the data or its interpretation. But although some of those I dealt with were unyielding, I generally had good success. My approach was pretty straightforward: “If these are the facts and this is the truth, then we proceed.”

What stands out for me about the Lab are its product and its people. The Lab has the largest, most accurate data set on agricultural runoff into rivers in the world. When governments, industry and modelers want real data, they come to Heidelberg. I would especially emphasize the people behind the scenes— their dedication, accuracy and thoroughness. They work ‘till it’s done.

Remegio (Rem) Confesor: Rem’s background as an agricultural engineer in the Philippines—he conducted research and taught at the Universities of the Philippines at Los Banos (1988-97) and Mindanao (1997-99)—prepared him well for his Ph.D. work in the Department of Agricultural and Biological Engineering at Pennsylvania State University (2004). He joined the NCWQR in 2008 after completing a four-year Post Doc in the Department of Agricultural Economics at Oregon State University. At Heidelberg, he uses watershed modeling to explore the effects of agricultural practices and climate change on nutrient and sediment exports from Lake Erie watersheds.

Modeling is a continuous process, a feedback between the understanding of science and the results of a model. The feedback helps sharpen both the science underlying a model and its application to complex real-world problems. Modeling is the only tool we have at our disposal to integrate economics, policy, hydrology, soil science, climate, etc. It is, and will continue to be, the technology by which land management decisions are made and it is therefore an increasingly central part of the NCWQR’s research efforts.

This is not to diminish the importance of the Lab’s monitoring work. Monitoring the concentrations of nutrients in water is not sexy and it has been looked down on [by some experimental scientists]—Is it really science if there’s no research question framed by a null hypothesis? But people have begun to realize that, much like medical monitoring of a person’s health, it is necessary. In fact, after 50 years the Lab’s data from monitoring starts to feel like a legacy.

Our historical strength has been sending technicians out to collect water samples for analyses back in the lab. What will be the Lab’s role in the future when, soon enough, everyone will be doing in situ monitoring? What will it then mean to be a “lab?” I believe we will become the standard for evaluating the accuracy and precision of in situ monitoring and we will be the group that compares everyone’s results, finding meaningful patterns and trends.

Laura Johnson: Laura has been researching topics in stream ecology since her undergraduate days at Virginia Polytechnic Institute where she was a member of the University’s Stream Team. After receiving her Ph.D. from Notre Dame in 2008 studying the effect of human land use on stream nutrient processing, she completed a Post Doc working on denitrifying bacterial
assemblages in agricultural streams (among other projects) at Indiana University in Bloomington. Johnson joined the NCWQR as a research scientist in 2013. Having focused much of her research on human impacts on the cycling of carbon and nitrogen in streams, she was well prepared to hit the ground running, lending a hand with the Lab’s studies on the export and riverine dynamics of phosphorus, nitrogen, and sediment. In January 2016, Johnson was named the Water Lab’s sixth Director (seventh, if you count Dave Baker’s two years as Interim Director).

I find streams and rivers a particularly stimulating area for biogeochemical research for a number of reasons: 1) they are the intermediaries between terrestrial and downstream aquatic ecosystems, 2) they combine zones of active biogeochemical cycling with the downstream movement of water, and 3) they are particularly threatened by human activities due to the density of streams and rivers within the landscape and the societal need for freshwater resources.

The August 2014 drinking water crisis in Toledo brought the Lab a lot more public visibility. Although Dave was still sought out for interviews and presentations, I increasingly found myself speaking on behalf of the Lab. I had no problem with that as I enjoy communicating science to the general public and environmental education has always been part of the Lab’s Mission. But preparing [for various speaking engagements] did take up a lot of my time and that has only increased since becoming Director.

In a number of interviews with agricultural extension agents and others, the opinion was voiced that the Lab’s recent emphasis on the stratification of phosphorus may not be as important a factor in addressing the off-field movement of dissolved phosphorus as soil health. Several added that it would be great if the Lab could hire a biologist with the ability to determine the relationship between soil health and phosphorus export in area tributaries to Lake Erie. Here’s Johnson’s response:

We often hear from agriculture experts that developing an organically rich, biologically diverse soil should reduce nutrient loss from farmed lands. There is no question that management for soil health—commonly involving the planting of winter cover crops—markedly enhances a field’s agricultural value. Land with improved soil health is less affected by drought and floods, produces better yields with less need for added nutrients and does lead to improved water quality through reduced losses of sediment and nitrogen. However, there is no strong evidence that it also leads to reduced dissolved phosphorus runoff.

For years, soil health advocates had cited a paper suggesting that “for every percentage increase in soil organic matter, the soil holds an additional inch of rain.” However since that paper was published, numerous studies have found no significant relationship between the organic matter content of soil and water retention. It may be, as is claimed by some, that the soil’s improved physical structure (rather than its organic component) is of importance to phosphorus retention. That is a topic scientists are actively investigating, but for now the Lab will retain its primary focus on those factors our data suggest to be impacting the movement of SRPs off farmed fields.

As we move forward, there is also the issue of maintaining a clear understanding of who we are as a Lab and the nature of our role [within the community of water quality research facilities]. We are a small operation housed within an undergraduate liberal arts institution with limited resources to support our work. We can’t—and don’t need to—do everything. For us to hire a biologist (or any new researcher) we have only two options: write a grant and then hire someone to do the work or hire someone to write the grant. While we have recently hired an additional
researcher (Nathan Manning) and will continue to take on Post Docs, we are also increasingly networking with other research groups. We are in the fortunate position where we can leverage our data and the skills of our scientists and technicians so as to encourage other professionals with complementary skill sets to work with us. In a way, it’s a sneaky way to get our hands on graduate students.

By working with researchers at other institutions, we are becoming part of the scaffolding of water resources scientists that is providing the structure to more efficiently address the region’s water quality issues, both the ones we currently face and those new challenges which will surely confront us in the future.

*Jakob Boehler:* In 2007, Heidelberg freshman Environmental Science major Jake Boehler took the elevator to the third floor of Gillmor Hall to see if there might be a chance for some part-time work in the Water Lab. Ten years later he received his M.A. from the School of Education, not for teaching school but in support of the educational mission of NCWQR where he had worked as a full-time technician since graduating in 2011. As a student, he learned his macroinvertebrate taxonomy working with Ken Krieger on the Cleveland Harbor hypoxia and Honey Creek Targeted Watershed projects. After the Honey Creek project’s conclusion, he began working on the Chemistry side, collecting field samples and learning field station maintenance from Jack. Over the next few years, Boehler gained experience in various of the Lab’s chemical analyses while continuing with some of Krieger’s macroinvertebrate studies. In 2017 Jake began teaching a few of the Biology Department’s non-majors’ labs and added directing the Sandusky River Watershed Coalition to his growing resume. Co-opting a baseball metaphor, it might be said that Jake has sort of become the Water Lab’s utility infielder.

After Dr. Krieger retired, my macroinvertebrate work was reduced to providing occasional support for several Biology professors, environmental outreach work with middle school groups [and SRWC volunteer groups] along with periodic contract taxonomic work for other institutions. Recently, however, I had the opportunity to work with Heidelberg geneticist, Kylee Spencer, on a new gene sequencing procedure for identifying members of a challenging group of sphaeriid clam species.

Although the focus of the Lab has always been its chemical analyses and I very much enjoy my current work, I do miss the biology. Krieger’s macroinvertebrate studies brought many students into the Lab and helped tie us more closely with the rest of the University. There’s discussion about rotating Environmental Science majors through the lab to provide them a bit of experience with the different activities in a water quality research lab, and also possibly finding ways for our staff to be more involved with teaching in the Biology and Chemistry curricula. I’d be all for that.

*Saptashati (Tania) Biswas:* Tania joined the NCWQR in 2015 as a Post-Doctoral Research Associate, leaving in 2017 to take a position as Research Lab Manager at the University of Nebraska-Lincoln. Prior to arriving at Heidelberg, she had received a M.Sc. in agricultural and environmental chemistry from the University of Kalyani (India) and her Ph.D. in

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*Boehler was lead author on two of the Old Woman Creek Taxonomic Atlases, for Copepods and Claderans.
†Previously and since its inception 18 years beforehand, the Coalition had been under management of the WSOS Community Action Commission (now the Great Lakes Community Action Partnership) based in Fremont, OH.
‡To a degree, this has occurred with adoption of the new Environmental Science and Sustainability major and Watershed Science Specialization in 2019.
Environmental Chemistry, Soil and Water Quality from the University of Maryland, College Park. Her primary focus in joining the Lab was to develop a suite of pesticide testing procedures using the Lab’s new LC-MS/MS machine. Although she made good progress on restoring the instrument to optimal functionality, the work was only partially completed by the time she moved to the University of Nebraska in Lincoln for a new position.

Tian Guo: Tian joined Rem Confesor in modeling agriculture-water quality interfaces as an NCWQR Post-Doctoral Research Associate in 2017. After receiving her Ph.D. in engineering and hydrological modeling from Purdue University in 2016 followed by a 10-month Post Doc at that institution, she has focused her attention at Heidelberg on developing field-scale nutrient export models and evaluating options for downscaling broad-scale climate models for use in predicting local conditions.

Watershed modelers are a small group and we are all looking at similar problems with similar sources of data and resources for analyzing that data. Over the last ten years, researchers have developed reasonably accurate models at different scales of differentiation. But downscaling watershed-level models to ever smaller scales has not been enough. In the future, we will need to move to individual farmers’ fields and to do so, modelers will have to develop working relationships with farmers. Successful models will need to incorporate realistic economic factors and it may be that government-sponsored pay-for-performance programs will be required to effect regional adoption of model-recommended land management options.

The goal of the Climate Change Project in the Lake Erie region is to [make the best possible] use of global climate models in generating regional Climate Impact Indicators using tourism as a dependent factor, with links to hydrologic and algal bloom models. Among the many problems with such a project is that the climate data on which the models are based are spotty and too often missing important sources of information, which requires some form of bias correction.

Nicole Kuhn: A Tiffin native, Nicole received her B.S. in Marine and Freshwater Environmental Biology from Ohio University. She began working at the NCWQR in February 2017 as a temporary replacement for Jake Boehler when his wife had their first child, and was delighted when offered the opportunity to convert to full time in May. Working with Ellen and Barb in the analytical chemistry lab Tuesday through Friday and helping to run the sample collection routes on Monday, Kuhn may prove to be one of the next generation of lab technicians that have played such an important role in the long-term success of the Water Lab. If so, she will have oversized shoes to fill.

Nathan Manning: Nate developed an appreciation for private liberal arts colleges during his undergraduate years at Wittenberg University in Springfield Ohio. After receiving his M.S. in wetland ecology at the University of Akron and serving as the Science Curriculum Developer for

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*An LCMS/MS is a liquid chromatography unit linked to two mass spectrometers. The LC separates the different chemical components in a water sample, which are then sent to the first MS. Here the sample is ionized and a “mass spectrum” is generated measuring the masses of the various compounds within the sample (allowing their identification). Typically, a second MS will focus on one “peak” within the first mass spectrum created by compounds with very similar mass characteristics. This provides increased sensitivity, enabling separate identification of compounds in the sample that would have been identified as the same compound if only the first MS had been used.
the Medina County Career Center, he was awarded his Ph.D. in 2013 from the University of Toledo, working with Christine Mayer and Jon Bossenbroek on an aquatic ecosystem modeling project examining the effects of various turbidity regimes on the growth and mortality of young-of-the-year yellow perch. He then completed two Post Docs at the University of Michigan, the first working on the Great Lakes Ecological Assessment and Mapping (GLEAM) Project exploring the impact of 50 stressors (environmental impacts like algal blooms, fishing pressure, various pollutants, etc.) on a dozen services (benefits to humans like recreation, fishing, shipping, beach use, etc.), and the second Post Doc developing algal bloom prediction models. In 2018, Manning joined the NCWQR which had been looking for someone to assist Laura with 4R and various other projects as the Directorship was taking up too much of her time. With his strong ecological modeling background, Nate’s skills are proving useful in addressing complex problems such as a stream metabolism study exploring how quickly streams of different size recover from disturbances like storm events.

I am a biologist who uses modeling to answer questions with a biological spin—in the past about community composition and early life stage mortality factors in fish. Along with my other projects here, I am currently developing a proposal with Laura to work with OSU and Kent State researchers to better inform SWAT† modeling of instream processing of nutrients. I would like to see my work eventually inform the application of the Lab’s research in helping to address Lake Erie’s algal bloom issues.

Besides the desirability of working at the renowned NCWQR—I had been using its data for most of my professional career—the potential for working with undergraduate students was a major factor attracting me to Heidelberg. Teaching is a primary driver for me. My brother graduated from Heidelberg and knowing that professors’ close interaction with their students has been a hallmark of the University, appealed to me greatly. From what I understand, Administration seems behind the idea of finding ways for the Water Lab’s people to be more involved with the students. I’d be very open to teaching full courses, especially if the new Watershed Sciences Specialization that’s being discussed comes into being.‡

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*Stream metabolic processes in aquatic systems are commonly measured in terms such as Gross Primary Productivity and Oxygen flux over a 24 hr period.
†The Soil and Water Assessment Tool (SWAT) is a USDA-supported public domain hydrologic model that is widely employed to measure the impact of land management practices within large complex watersheds
‡It did, and Manning is to be teaching some of the coursework in the new Environmental Science and Sustainability major.

# Appendix A. NCWQR Staff and Student Research Assistants

Table 1. Staff members employed by the Water Laboratory, 1969-2019.

<table>
<thead>
<tr>
<th>Years</th>
<th>Staff member</th>
<th>Principal occupation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969-2012</td>
<td>Jack W. Kramer</td>
<td>Lab Manager</td>
</tr>
<tr>
<td>1969-99</td>
<td>David Baker</td>
<td>Director</td>
</tr>
<tr>
<td>1974-75</td>
<td>Gail Wolfe (Hemsoth)</td>
<td>Research Asst.</td>
</tr>
<tr>
<td>1976-79</td>
<td>Bayliss &quot;Rock&quot; Prater</td>
<td>Assoc. Director</td>
</tr>
<tr>
<td>1976-present</td>
<td>D. Ellen Ewing</td>
<td>Lab Manager</td>
</tr>
<tr>
<td>1977-82</td>
<td>Mary Dobstaff</td>
<td>Research Asst.</td>
</tr>
<tr>
<td>1978-198?</td>
<td>M. Patricia Hillmer</td>
<td>Administrative Asst.</td>
</tr>
<tr>
<td>1978-2014</td>
<td>R. Peter Richards</td>
<td>Dir. 1999-02</td>
</tr>
<tr>
<td>1978-86</td>
<td>Francine Turose-Wiese</td>
<td>Research Asst.</td>
</tr>
<tr>
<td>1978-present</td>
<td>Barbara L. Merryfield</td>
<td>Research Asst.</td>
</tr>
<tr>
<td>198?-19??</td>
<td>June Huss</td>
<td>Administrative Asst.</td>
</tr>
<tr>
<td>1986-present</td>
<td>Nancy Miller</td>
<td>Business Manager</td>
</tr>
<tr>
<td>1987-95</td>
<td>Laura Wallrabenstein</td>
<td>Research Asst.</td>
</tr>
<tr>
<td>1989-90</td>
<td>Wang Gui Lin</td>
<td>Visiting professor</td>
</tr>
<tr>
<td>1997-06</td>
<td>Josie Setzler</td>
<td>Research Scientist</td>
</tr>
<tr>
<td>2000-01</td>
<td>Sabine Grunwald</td>
<td>Research Scientist</td>
</tr>
<tr>
<td>2002-05</td>
<td>Timothy Loftus</td>
<td>Director</td>
</tr>
<tr>
<td>2005-07</td>
<td>David Baker</td>
<td>Interim-Director</td>
</tr>
<tr>
<td>2006-08</td>
<td>Anne Stearns</td>
<td>Quality Control</td>
</tr>
<tr>
<td>2006-present</td>
<td>Aaron Roerdink</td>
<td>Quality Control</td>
</tr>
<tr>
<td>2007-10</td>
<td>Gary Winston</td>
<td>Director</td>
</tr>
<tr>
<td>2007-10</td>
<td>John Crumrine</td>
<td>Env. Extension</td>
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<tr>
<td>2008-present</td>
<td>Remegio B. Confesor, Jr.</td>
<td>Research Scientist</td>
</tr>
<tr>
<td>2011-present</td>
<td>Jakob Bohler</td>
<td>Research Asst.</td>
</tr>
<tr>
<td>2013-present</td>
<td>Laura T. Johnson</td>
<td>Dir. 2016-present</td>
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<tr>
<td>2015-17</td>
<td>Saptashati &quot;Tania&quot; Biswas</td>
<td>Postdoc</td>
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<tr>
<td>2017-present</td>
<td>Tian Guo</td>
<td>Postdoc</td>
</tr>
<tr>
<td>2018-present</td>
<td>Nate Manning</td>
<td>Research Scientist</td>
</tr>
<tr>
<td>2018-present</td>
<td>Nicole Kuhn</td>
<td>Research Asst.</td>
</tr>
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</table>
Table 2. Student research assistants employed by the Water Laboratory, 1969-2019.

Heidelberg’s records for students who worked as part-time research assistants prior to the year 2000 are unavailable. Information in this table for student workers before that time is based on the memories of long-time staff members Ellen Ewing, Barb Merryfield and Nancy Miller. Thus, some number of former student workers have, unfortunately, been unintentionally omitted from this listing.

When known, the years of a student’s employment are given in un-italicized numbers. Where this is not known his/her year of graduation from Heidelberg is given as an italicized number. If that Heidelberg student did not graduate, his/her last date of attendance is given in brackets. An “x” in the year column indicates that the Registrar has no record of the student having attended Heidelberg, most commonly because s/he had been a summer employee who attended a different college during the academic year.

<table>
<thead>
<tr>
<th>Year(s)</th>
<th>Student</th>
<th>Year(s)</th>
<th>Student</th>
<th>Year(s)</th>
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<tr>
<td>1973-74</td>
<td>Beckert, Clinton</td>
<td>1989</td>
<td>Nicewander, Julie</td>
<td>x-1999</td>
<td>Fry, Peggy</td>
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<td>1975</td>
<td>Walton, Carol Beckert</td>
<td>1990</td>
<td>Consagro, Christina</td>
<td>x-1999</td>
<td>Ferris, Tristan</td>
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<td>1975</td>
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<td>1990</td>
<td>Ross, Lloyd</td>
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<td>Hothen, Seth D.</td>
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<td>1974-77</td>
<td>Theller, Becky Goetz</td>
<td>1991</td>
<td>Chaffee, Maggie</td>
<td>?-2000</td>
<td>Chudzinski, Abigail</td>
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<td>1975-76</td>
<td>Lee, Susan Regan</td>
<td>1991</td>
<td>Rhodes, John</td>
<td>?-2000</td>
<td>Deshaies, Emily E.</td>
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<td>1976</td>
<td>Rindfuss, Robert</td>
<td>1991</td>
<td>Sendelbach, Kevin</td>
<td>?-2000</td>
<td>Hiser, Erica</td>
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<td>x-1976</td>
<td>Kahn, Agnes</td>
<td>1992</td>
<td>Egan, Todd</td>
<td>?-2000</td>
<td>Roby, Stacie L.</td>
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<td>1978</td>
<td>Leslie, Richard</td>
<td>1996</td>
<td>Rose, Thomas</td>
<td>2000-01</td>
<td>Bell, Samantha</td>
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<td>1980</td>
<td>Thomas, Jan</td>
<td>1996-99</td>
<td>Creque-Thomas, Sara</td>
<td>2001-02</td>
<td>Porcello, Kelly S.</td>
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<td>1984</td>
<td>Blake, Gail</td>
<td>1998</td>
<td>Trissell, Liberty</td>
<td>2001-03</td>
<td>Harris, Justin D.</td>
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<td>1986</td>
<td>Fox, Molly</td>
<td>1999</td>
<td>Shields, Laura</td>
<td>2002</td>
<td>Wain, Rachael A.</td>
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<td>1986-87</td>
<td>Boehm, Michael</td>
<td>1999</td>
<td>Saxton, James</td>
<td>2002-03</td>
<td>Zimmerman, Brian J.</td>
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Table 2. Student research assistants (continued).

<table>
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<tr>
<th>Year(s)</th>
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<th>Year(s)</th>
<th>Student</th>
<th>Year(s)</th>
<th>Student</th>
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<td>2004-05</td>
<td>Hayes, Amanda L.</td>
<td>2010</td>
<td>Langenkamp, Scott G.</td>
<td>2015-17</td>
<td>Chong, Bryce I.</td>
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<td>2004-06</td>
<td>Davis, Michael W.</td>
<td>2010</td>
<td>Olewiler, Joshua J.</td>
<td>2016</td>
<td>Blum, Danielle E.</td>
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<td>2004-08</td>
<td>Ryan, James P.</td>
<td>2010-11</td>
<td>Fallon, Michael L.</td>
<td>2016</td>
<td>Lester, Emilee D.</td>
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<td>2005</td>
<td>Richmond, Susan L.</td>
<td>2011-12</td>
<td>Bensman, Kyle J.</td>
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<td>Boehler, Christopher T.</td>
<td>2011-14</td>
<td>Cochran, Jacob L.</td>
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<td>Smith, Judy</td>
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<td>2006-09</td>
<td>Boulee (Thomas), Kristi</td>
<td>2011-12</td>
<td>Reitenbach, Barbara Purviance</td>
<td>2018-19</td>
<td>McNabb, Anna E.</td>
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<td>2007</td>
<td>Hurrell, George L.</td>
<td>2012</td>
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<td>Nainiger, Austin J.</td>
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<td>2007-09</td>
<td>Lamoreaux, Matthew</td>
<td>2012-13</td>
<td>Gordon, Jeffrey D.</td>
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<td>2008</td>
<td>DeRosa, Rachael M.</td>
<td>2012-14</td>
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<td>2008-09</td>
<td>Xu, Yimin</td>
<td>2013-14</td>
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<td>2008-09</td>
<td>Zeng, Dian</td>
<td>2013-14</td>
<td>Parker, Sarah E. M.</td>
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<td>Webb, Christie</td>
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<td>2008-10</td>
<td>Hedrick, Candice E.</td>
<td>2014-15</td>
<td>Tussing, Matthew K.</td>
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<td>Slater, Lisa</td>
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<td>2008-11</td>
<td>Laubender, Benjamin</td>
<td>2015</td>
<td>Keller, Jordan E.</td>
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<td>Behm, Chris</td>
</tr>
</tbody>
</table>
Appendix B. Sample Annual Report

Dave Baker prepared seven Annual Reports summarizing the Lab’s principal activities and budgets for fiscal years 1988-89 through 1994-95. After a hiatus of 16 years, Ken Krieger assembled reports for each of his five years as Director, from 2010-2011 to 2014-2015.

The following overview of the main topics covered in Krieger’s 2012-2013 Annual Report can serve as representative of the NCWQR’s long-term and expanding activities during this period.

Overview of the 2012-2013 NCWQR Annual Report

**Mission:** Our mission is to promote the sustainable use of water and soil resources while striving to protect ecosystem integrity.

**Goals for 2013-2014:**
- Continue to seek input from the Advisory Council and others to develop research programs and more diverse and stable funding for the NCWQR.
- Actively recruit corporate, foundation, and agency members into a funding coalition to provide a more dependable financial footing for the HTLP.
- Work with the Office of Institutional Advancement to increase the two endowments designated for the NCWQR.
- Enhance participation in the Private Well Testing Program.
- Continue our transition to a new generation of scientists and technicians.
- Continue to revise and update the NCWQR website.
- With the new instrumentation now installed in the NCWQR, expand our chemical analyses to additional pesticides, pharmaceuticals and personal care products (PPCPs), And other compounds of growing environmental concern.

**Permanent staff:**
- David B. Baker, Director Emeritus, Prof. Emeritus of Biology, 1966, part-time
- Jakob A. Boehler, Research Assistant, 2011
- Remegio B. Confessor, Jr., Research Scientist (watershed modeling), 2008
- D. Ellen Ewing, Laboratory Manager, 1976
- Laura T. Johnson, Research Scientist (aquatic systems nutrient processing), 2013
- Jack W. Kramer, Laboratory Manager, Emeritus, 1969, part-time
- Kenneth A. Krieger, Director, Professor of Biology (invertebrate ecology), 1978
- Barbara J. Merryfield, Research Assistant, 1978

*Keeping track of the Lab’s annual activities and financial dealings is complicated by how “a year” is defined. For research purposes, the Water Year begins on Oct 1, as does the Federal Budget Year. The Fiscal Year for Ohio, Heidelberg and the Water Lab starts on July 1, while Sea Grant Program support dates from Sep 1. Industrial support is typically keyed to start on Jan 1 as are publications and presentations. Finally, over the years, the start of the University’s Academic Year has varied from one to three weeks before Labor Day.*
• Nancy L. Miller, Business Manager, Well Testing Program Manager, 1986
• R. Peter Richards, Senior Research Scientist (statistics, hydrology), 1978, part-time
• Aaron Roerdink, Analytical Chemist, Asst. Prof. of Chemistry, 2006, part-time

Highlights of Fiscal Year 2013:
• We received 13 grants and 5 others were pending as of 30 June 2013.
• We conducted 18 separately funded projects.
• We drove two routes weekly to collect water samples at our 11 tributary loading stations in northwestern and west-central Ohio and maintained automated samplers and pumping systems at 14 of our 16 active stations throughout Ohio and southeastern Michigan. We began operation of a new station on Coldwater Creek in the Grand Lake Saint Marys (GLSM) watershed and another on Beaver Creek immediately below the GLSM dam.
• We analyzed 8,881 surface water, sediment, and tissue samples and 350 well water samples. Compounds tested included nutrients, microcystin (algal) toxin, dissolved metals and volatile organic compounds (VOCs). An additional 527 surface water samples were analyzed for pesticides. We posted the results for nutrients and suspended sediment for most of our tributary monitoring stations on our data download website.
• We completed analysis of aquatic macroinvertebrate samples for the USEPA Targeted Watershed Study and continued to analyze macroinvertebrate samples for the Ohio EPA.
• We made 26 presentations at professional conferences, meetings of civic groups, and other events.
• The staff published 8 peer-reviewed articles and 1 report, and two articles were undergoing revision.
• Senior researchers reviewed numerous proposals and journal manuscripts; the Director continued to serve as associate editor of a journal.
• Staff members taught 3 upper-level courses in the Environmental Science and Chemistry curricula.
• We employed 7 students and advised 4 students on independent studies, including a summer (2013) intern from Brazil.
• The NCWQR staff conducted 6 workshops and numerous lab tours.
• In October 2012, Heidelberg University enlisted the services of Public Sector Advisors in Columbus, Ohio, to assist the NCWQR in obtaining new sources of funding and enhanced recognition for the NCWQR and the University.
• Also in October, “The Pond” was dedicated on the Heidelberg campus near Gillmor Science Hall.
• We hosted meetings of the Advisory Council in December 2012 and July 2013.
• In February 2013, we held a legislators’ day that included presentations and a laboratory tour for Ohio and U.S. Senators and Representatives and their aides, organized by Bog Doyle of Public Sector Advisors.
• We hosted a visit by Dr. Helen Jarvie in March 2013. Dr. Jarvie is principal scientists in hydrochemistry at the Centre for Ecology & Hydrology in Wallingford, England, and has collaborated and published with the NCWQR.
Ongoing grants and contracts received before July 2012:

- Great Lakes Protection Fund: A phosphorus soil test metric for reducing dissolved phosphorus loads.
- National Oceanic and Atmospheric Administration: Ecological Forecasting.
- U.S. Environmental Protection Agency: The Honey Creek targeted watershed project.
- National Science Foundation (through the University of Michigan): Extreme events impacts on water quality in the Great Lakes: prediction and management of nutrient loading in a changing climate.
- Buffalo State College (funded by USEPA Great Lakes National Program Office): Lake Erie nearshore-offshore nutrient study.
- Miami Conservancy District: Monitor nutrient concentrations in the Great Miami River at Miamisburg.
- The Fertilizer Institute: Support for Heidelberg’s Tributary Loading Program.
- Ohio Department of Natural Resources: Operation of monitoring station on Coldwater Creek, a tributary of Grand Lake Saint Marys.
- Ohio Environmental Protection Agency (Great Lakes Restoration Initiative): Invertebrate identification and enumeration for Ohio EPA’s nearshore biomonitoring program.
- Ohio Water Development Authority: Continued operation of monitoring station on Chickasaw Creek, a tributary of Grand Lake Saint Marys.
- IPM Institute of North America (funded through the Great Lakes Protection Fund): Sandusky River monitoring and SWAT modeling.
- IPM Institute of North America (funded by USDA Natural Resources Conservation Service): Applying Ag-retail muscle to priority challenges in the Great Lakes Basin.
- Syngenta Crop Protection, Inc.: Pesticide monitoring program.
- Monsanto: Pesticide monitoring program.
- Dow AgroSciences: Pesticide monitoring program.

New grants and contracts received in fiscal year 2012-2013:

- Ohio Department of Natural Resources: Installation and operation of new monitoring station on Beaver Creek below dam at Grand Lake Saint Marys.
- Ohio Department of Natural Resources: Installation and operation of new monitoring station on Coldwater Creek a tributary of Grand Lake Saint Marys.
- Ohio Water Development Authority: Continued operation of monitoring station on Chickasaw Creek, a tributary of Grand Lake Saint Marys.
- Miami Conservancy District: Continued monitoring of nutrient concentrations in the Great Miami River at Miamisburg.
- The Andersons, Inc. Charitable Foundation: Continued support for Maumee River loading station.
• The Fertilizer Institute: Continued support for Heidelberg’s Tributary Loading Program
• Syngenta Crop Protection, Inc.: Continued support and special study, pesticide monitoring program.
• Monsanto: Continued support for pesticide monitoring program.
• Dow AgroSciences: Continued support for pesticide monitoring program.
• U.S. Department of Agriculture, Natural Resources Conservation Service, Conservation Innovation Grant (through Ohio Environmental Council): Comprehensive analysis of CIG projects conducted in Ohio.
• International Joint Commission (through Wayne State University): Chapter in Lake Erie Ecosystem Priority (LEEP) report on response of phosphorus runoff to agricultural best management practices.
• University of Michigan Water Center (through U. of Toledo): A Bayesian hierarchical modeling approach for comparing water quality measurements from different sources.

Grant proposals pending as of 30 June 2013:
• U.S. Department of Agriculture, Natural Resources Conservation Service, Conservation Innovation Grant: Verification and enhancement of NRCS Nutrient Tracking Tool (NTT) with a suite of best management practices (BMPs).
• U.S. Department of Agriculture, Agriculture Research Service: Long-Term Agro-ecosystem Research (LTAR) Network: Eastern Corn-Belt LTAR Node Covering the Ohio River Basin and Great Lakes Region (submitted collaboratively with the Soil Drainage Research Unit, USDA ARS, Columbus OH and the National Soil Erosion Research Laboratory, USDA ARS, West Lafayette IN.
• William Bingham Foundation: Monitoring water quality in Lake Erie Tributaries.
• University of Michigan Water Center: Assessment of nutrient and sediment reduction efforts in the Great Lakes.
• University of Michigan Water Center: Improving accuracy of agricultural watershed monitoring and modeling to better support programs for reduction of sediment and nutrient export.

In conjunction with the Lab’s notable success in obtaining a wide diversity of grants in support of its programs, another indication of the Lab’s active and highly regarded research program is the number of fruitful connections its staff members have developed with researchers at other institutions. The 2013 Annual Report illustrated this in an appendix naming an impressive list of investigators who collaborated with NCWQR researchers during the 2012-2013 fiscal year—31 collaborators from institutions in Ohio, 78 from other U.S. institutions and 8 from organization in other countries.

Undergraduate students employed in the NCWQR:
• Cody M. Buhrman, Env. Sci. major, Water Resources track, 2014 expected graduation
• Jacob L. Cochran, Env. Sci. major, Biology track, 2014 expected graduation
• Susan E. Daniel, Env. Sci. major, Water Resources track, 2013 graduation
• Jeffrey D. Gordon, Env. Sci. major, Biology track, 2013 graduation
• Erin Gorrell, Biology major, Chemistry minor, 2014 expected graduation
• Christopher A. Osborne, Env. Sci. major, Biology track, 2014 expected graduation
• Jeffrey D. Peck, Env. Sci. major, Water Resources track, 2013 graduation
Undergraduate students research advising:

- Rem Confessor:
  Christopher Osborne, Modeling Best Management Practices in the Sandusky River Watershed using GIS and the SWAT model

- Laura Johnson:
  Rafael Ishikawa (Brazil Scientific Mobility Program Intern, summer 2013), A comparison of data collected using in situ probes with water quality data from the NCWQR

- Ken Krieger:
  Susan Daniel, Assessment of habitats susceptible to invasion of the Western Lake Erie Basin by New Zealand mud snail (*Potamopyrgus antipodarum*)

- Aaron Roerdink:
  Jeffrey Peck, A comparison of water quality above and below Hoover Reservoir Dam, Franklin County, Ohio

Graduate students research advising:

- Ken Krieger:
  Rachel Kuhaneck, M.S. Biology, Ecology track, Univ. of Toledo (Advisors T.B. Bridgeman and C. Mayer), Thesis: Vegetation on Riprapped Shorelines: Implications for Invertebrate Communities and Restoration of Nearshore Areas

- Ken Krieger:
  Justin Selden, M.S. Biology, Ecology track, Univ. of Toledo (Advisor TJ. Gottgens), Thesis: The Effect of Dredging on Fish Communities in Agricultural Streams in Crawford, Sandusky and Seneca Counties of Ohio

Heidelberg courses taught by NCWQR staff members, 2012-201

- Aaron Roerdink: Quantitative Analysis (CHM 305), Environmental Chemistry (CHM 205)
- Ken Krieger: Limnology (ENS 323), Water Pollution Biology (BIO 324)

The NCWQR in the News

Five articles in the Columbus *Dispatch* and one in the Tiffin *Advertiser-Tribune* discussed NCWQR research findings; some articles were printed by newspapers across the U.S.

Budget—Fiscal year 2012-2014 Expenses:

Net expenses totaled $1,055,976.26 and net revenues totaled $1,060,316.81, leaving a positive balance of $4,340.55 in our general fund to be added to our reserve funds carried over from prior years. Our budget was allocated to 22 different funds [which are listed in the Summary of Revenue table, below].

Salaries of our permanent staff members totaled $452,627.52 and in addition we paid $12,819.94 in student wages. Fringe benefits for staff and students totaled $125,865.16. Therefore, total salaries, wages and benefits amounted to $591,312.62. Other major expense

*Descriptions in this and the following section are quoted from the 2012-2013 Annual Report.*
categories are shown in the table below. “Outside services” of $239,858.48 mostly consisted of pass-through funds ($200,048) from the USEPA Targeted Watershed grant to the Seneca Soil and Water Conservation District for services they provided, including a full-time technician, and for payments to farmers for implementation of agricultural best management practices. The Table and graph show NCWQR expenses according to major categories.

<table>
<thead>
<tr>
<th>Expenses by Major Categories</th>
<th>In FY 2012-2013</th>
</tr>
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<tbody>
<tr>
<td>Salaries</td>
<td>$452,628</td>
</tr>
<tr>
<td>Student Wages</td>
<td>12,820</td>
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<tr>
<td>Fringe Benefits</td>
<td>125,865</td>
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<td>Supplies</td>
<td>57,248</td>
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<td>Travel</td>
<td>31,459</td>
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<tr>
<td>Mileage</td>
<td>16,849</td>
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<tr>
<td>Postage/Shipping</td>
<td>10,323</td>
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<tr>
<td>Maintenance</td>
<td>23,978</td>
</tr>
<tr>
<td>Agreements</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>7,121</td>
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<tr>
<td>Equipment &gt;$1K</td>
<td>35,187</td>
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<tr>
<td>Outside Services</td>
<td>239,858</td>
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<tr>
<td>Heidelberg Univ. (I.C.)*</td>
<td>35,000</td>
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<td>Public Sector Advisors</td>
<td>20,000</td>
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<tr>
<td>Other</td>
<td>6,639</td>
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<tr>
<td>Total</td>
<td>$1,055,976</td>
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</table>

*Amount of total indirect costs (I.C.) received by NCWQR in FY 2012-2013 that was returned to the University.

Expenses this year included a proportion of fees paid to Public Sector Advisors in Columbus, OH.

Budget—Fiscal year 2012-2014 Revenue:

<table>
<thead>
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<th>NET REVENUE BY SOURCE, FY 2012-2013</th>
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<tr>
<td>Federal</td>
</tr>
<tr>
<td>State of Ohio</td>
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<tr>
<td>Other Governmental</td>
</tr>
<tr>
<td>Foundations</td>
</tr>
<tr>
<td>For-Profit Corporations</td>
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<tr>
<td>Other</td>
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<td><strong>ALL SOURCES</strong></td>
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<table>
<thead>
<tr>
<th>NET REVENUE BY ACTIVITY, FY 2012-2013</th>
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<tbody>
<tr>
<td>Heidelberg Tributary Loading Program (HTLP)</td>
</tr>
<tr>
<td>Tributary Data Applications</td>
</tr>
<tr>
<td>Other Research</td>
</tr>
<tr>
<td>Well Testing</td>
</tr>
<tr>
<td>Contract Analyses</td>
</tr>
<tr>
<td><strong>ALL ACTIVITIES</strong></td>
</tr>
</tbody>
</table>
We were able to include indirect costs (overhead) as part of our revenue for many of our grants and contracts, for which we received $173,556.52. Of the total indirect cost revenue, we returned $35,000 to Heidelberg University for facilities and administrative costs. The University permits the NCWQR retain the remainder of indirect cost revenue to apply to needs not covered by specific grants such as equipment and vehicle repair and replacement, and grant writing.

**Summary of Revenue for Fiscal Year 2012-2013**

<table>
<thead>
<tr>
<th>Fund</th>
<th>Project Reference</th>
<th>Funding Source</th>
<th>Net Revenue</th>
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<tr>
<td>General and Contract Analyses</td>
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<td>($13,902.88)</td>
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<td>1150</td>
<td>General</td>
<td>NCWQR</td>
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<tr>
<td>1160</td>
<td>Contract Work</td>
<td>Various sources</td>
<td>67,223.67</td>
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<tr>
<td>2217</td>
<td>Groundwater Testing</td>
<td>Citizens, health depts., etc.</td>
<td>50,945.39</td>
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<td><strong>Subtotal</strong></td>
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<td>104,266.18</td>
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<tr>
<td>For-Profit Corporations</td>
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<tr>
<td>1152</td>
<td>Pesticides</td>
<td>Dow AgroSciences, Monsanto, Syngenta</td>
<td>82,019.79</td>
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<td>2309</td>
<td>Maumee River</td>
<td>The Andersons, Inc., The Fertilizer Institute</td>
<td>21,663.20</td>
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<tr>
<td><strong>Subtotal</strong></td>
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<td></td>
<td>103,682.99</td>
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<tr>
<td>Federal Funding</td>
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<tr>
<td>2127</td>
<td>Buff State NSOS</td>
<td>USEPA GLNPO</td>
<td>22,274.65</td>
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<td>2128</td>
<td>Water Sustainability</td>
<td>NSF-WSC (Univ. Michigan)</td>
<td>58,856.83</td>
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<tr>
<td>2129</td>
<td>Phosphorus BMPs</td>
<td>USEPA (through UC)</td>
<td>12,000.00</td>
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<tr>
<td>2157</td>
<td>UIM ECO/ORE</td>
<td>USDA NRCS</td>
<td>5,729.17</td>
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<tr>
<td>2159</td>
<td>Targeted Watershed</td>
<td>USEPA Region V</td>
<td>210,193.88</td>
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<tr>
<td>2407</td>
<td>BMP Modeling</td>
<td>USDA NRCS (through PPM)</td>
<td>8,323.40</td>
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<td><strong>Subtotal</strong></td>
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<td>317,377.93</td>
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<td>State of Ohio Funding</td>
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<tr>
<td>2281</td>
<td>L. Erie Biomonitors</td>
<td>Ohio EPA</td>
<td>31,442.13</td>
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<tr>
<td>2282</td>
<td>Tributary Monitoring</td>
<td>Ohio DNR (state line item)</td>
<td>250,000.00</td>
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<tr>
<td>2284</td>
<td>Coldwater Creek</td>
<td>Ohio DNR</td>
<td>37,283.57</td>
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<td>2285</td>
<td>ODNR-Beaver Creek</td>
<td>Ohio DNR</td>
<td>6,802.74</td>
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<tr>
<td><strong>Subtotal</strong></td>
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<td>325,528.44</td>
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<tr>
<td>Other Governmental Sources</td>
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<tr>
<td>2249</td>
<td>Raisin River</td>
<td>Michigan DEQ</td>
<td>2,845.78</td>
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<tr>
<td>2280</td>
<td>Tributary Monitoring</td>
<td>OWDA</td>
<td>4,749.85</td>
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<td>2283</td>
<td>Chickasaw Creek</td>
<td>OWDA</td>
<td>31,566.71</td>
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<td>2405</td>
<td>Great Miami River</td>
<td>Miami Conserv. District</td>
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<tr>
<td><strong>Subtotal</strong></td>
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<td>64,531.76</td>
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<tr>
<td>Foundations</td>
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<tr>
<td>2275</td>
<td>Soil Phosphorus</td>
<td>GLPF</td>
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<tr>
<td>2406</td>
<td>BMP Modeling</td>
<td>GLPF (through PPM)</td>
<td>51,825.71</td>
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<tr>
<td><strong>Subtotal</strong></td>
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<td>144,929.53</td>
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<tr>
<td><strong>Total Net Revenue</strong></td>
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<td>$1,060,316.83</td>
</tr>
<tr>
<td><strong>Total Net Expenses</strong></td>
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<td></td>
<td>$1,055,976.26</td>
</tr>
<tr>
<td><strong>End of Year Balance</strong></td>
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<td></td>
<td>$4,340.57</td>
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<tr>
<td>Carryover Brought Forward from FY 2012</td>
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<td></td>
<td>$136,392.85</td>
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<tr>
<td>Carryover Brought Forward to FY 2014</td>
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<td></td>
<td>$140,733.42</td>
</tr>
<tr>
<td>Deferred Revenue to FY 2014 (in addition to Net Revenue above)</td>
<td></td>
<td></td>
<td>$127,850.17</td>
</tr>
<tr>
<td>Deferred Expense to FY 2014 (in addition to Net Expenses above)</td>
<td></td>
<td></td>
<td>$36,208.38</td>
</tr>
</tbody>
</table>
Current Research and Monitoring Activities:*

- The Heidelberg Tributary Loading Program (HTLP)
  The HTLP is the flagship research and monitoring program of the NCWQR. It began in 1974 and continues to be a specialized water quality monitoring program designed to measure accurately the total amounts (loads) of pollutants exported from watersheds by rivers and creeks...More than 50% of Ohio’s land area is upstream from HTLP stations in both the Lake Erie and Ohio River basins. The current network of 16 stations† is unique within the United States in terms of its detail and duration.

- Private Well Testing Program
  The Private Well Testing Program was developed in 1987 to track nitrate (and later pesticide) concentrations in Ohio private drinking water wells. In 1990, under the sponsorship of the American Farm Bureau Federation, the program was expanded to other states. Since then over 25,000 well have been tested from all of Ohio’s 88 counties, and samples have been analyzed from nearly 35,00 wells in over 350 counties from 26 other states.

- Phosphorus and Agricultural Nonpoint-Source Pollution Studies
  - The Honey Creek/Sandusky River Targeted Watershed Project: Water Quality Improvement through Adaptive Management
    This five-year USEPA-funded project began in 2008. The project goal is to implement Best Management Practices (BMPs) in the Honey Creek Watershed with the intent of reducing the amount of dissolved phosphorus and nitrate that leave the landscape and move progressively from ditches to headwater streams to Honey Creek, the Sandusky River, and ultimately Lake Erie.

  - A Phosphorus soil Test Metric for Reducing Dissolved Phosphorus Loads
    The Great Lakes Protection Fund provided a 5.5 year grant to the NCWQR beginning in October 2007 for this project. Working with local soil and water conservation districts, Certified Crop Advisors, fertilizer dealers, local farmers, and a soil testing laboratory, data have been collected on the stratification of phosphorus in cropland soils for more than 1,300 fields in this area...In a second part of this grant, we have developed a “toolbox” of Best Management Practices (BMPs) to reduce the runoff of dissolved reactive phosphorus.

  - Ecological Forecasting (ECOFORE 2006): Hypoxia Assessment in Lake Erie
    This five-year project, funded at the University of Michigan by NOAA-CSCOR, officially finished in 2011 but continued into this reporting period with two years of no-cost extension, ending in September 30, 2013. The goal of the project was to build a suite of models that link land use and weather with tributary inputs and circulation patterns in Lake Erie and finally with ecological models of Lake Erie, to

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*This section includes excerpts taken from longer descriptions of these programs.
†At this writing the NCWQR’s HTLP network operates 18 stations.
determine the relative importance of changes in agricultural land management practices, climate change, and invasive species (zebra mussels) in explaining recent increases in hypoxia in Lake Erie’s central basin. The linked models are also being used to explore implications predicted climatic shifts during the next century.

○ Extreme Events Impacts on Water Quality in the Great Lakes: Prediction and Management of Nutrient Loading in a Changing Climate
  This five-year project funded at the University of Michigan by NSF’s Water Sustainability and Climate program started in October 2010. Building on the EcoFore project, the goal of this project is to use suites of models similar to those of EcoFore to explore the implications of projected climate change for the extent and abundance of harmful algal blooms in the western basin of Lake Erie and consequences for the productivity of the Lake Erie ecosystem, particularly the fisheries.

○ Forecasting Harmful Algal Blooms in Lake Erie’s Western Basin
  Working with NCWQR data from the Maumee River, Dr. Richard Stumpf of NOAA developed and evaluated a number of statistical models to predict [algal] bloom severity [in the western basin of Lake Erie]; the most successful model used discharge or phosphorus loading during March through June as predictors. NCWQR staff members worked with Stumpf to provide Maumee data for 2012 on a near real-time basis, leading to a successful prediction in July that the 2012 algal bloom would be a small one…The [2013] bloom appears to have exceeded the predicted size, perhaps due to heavy rain in early June, suggesting the need to refine the models.

○ Watershed Modeling and River Monitoring in Collaboration with IPM Institute of North America
  The BCWQR was subcontracted with the IPM Institute of North America on two grants that ended in 2013. One grant, from the USDA NRCS, was titled “Demonstrate a New Comprehensive Model to Increase Adoption to Improve Water Quality and Agricultural Land Economics on Critical Agricultural Lands.” The second grant, from the Great Lakes Protection Fund, was titled “Transforming our Approach to Generate Conservation Benefits from Agriculture”…We developed a user-friendly spreadsheet calculator/tool to predict nutrient (phosphorus and nitrogen) losses from a field using established efficiencies of implemented Best Management Practices (BMPs)…We also developed a high-resolution map of the Sandusky watershed based on the Siol and Water Assessment Tool (SWAT) model output. The map can be used to identify critical areas that are most sensitive to BMP implementation in reducing total phosphorus (TP) and dissolved reactive phosphorus (DRP) exports. The NRCS subaward ended in September 2013 and the GLPF grant ended in October 2013.
- Biological Studies
  - Responses of Aquatic Biological Communities to Land-Use and Ditch Maintenance Practices in Agricultural Landscapes
    As part of the Honey Creek/Sandusky River Targeted Watershed Project (see above), this five-year study was aimed at understanding how quickly, and to what extent, the aquatic habitats of maintained [agricultural] ditches become more complex and develop...beneficial [fish and invertebrate] communities in response to a variety of Best Management Practices (BMPs). Each summer and fall from 2008 through 2011, biologists surveyed fish and invertebrates in 20 segments of maintained ditches in the Sandusky and nearby watersheds. Fish were sampled by University of Toledo biologists (headed by Dr. Hans Gottigens), and NCWQR biologists sampled invertebrates. In 2012-2013 the sample analyses were completed, and during a sixth (no-cost extension_ year, the aquatic macroinvertebrate data are being analyzed using multivariate techniques to detect relationships between invertebrate and fish community characteristics and landscape and ditch management practices.

  - Analysis of Aquatic Macroinvertebrates for Ohio EPA’s Lake Erie Nearshore Monitoring Program
    The NCWQR contracted in 2011 with the Ohio EPA Division of Surface Water to perform laboratory analysis of benthic invertebrate samples as part of a Lake Erie nearshore monitoring program initiated with funding from the Great Lakes Restoration Initiative. We analyzed approximately 100 grab samples of bottom mud and 20 artificial substrate (Hester-Dendy) samples accompanied by qualitative samples collected by Ohio EOA in 2011 and 2012…The results from the Hester-Dendy samples will be compared to the grab samples to determine the value of using alternative index organisms or groups in the lake as opposed to those applied to tributaries.
Appendix C. The Great Lakes Water Quality Agreement

In 1972, Richard Nixon and Pierre Trudeau signed an executive agreement committing the U.S. and Canada to abide by the Great Lakes Water Quality Agreement (GLWQA), which had been based on research compiled by the International Joint Commission (IJC). Since then, efforts to manage pollution in the Great Lakes (especially Lake Erie’s problems with eutrophication) have co-evolved with the science underpinning those efforts.* In listing the Agreement’s initial water quality objectives, Article II (e) stated that Great Lakes waters should be:

Free from nutrients entering the waters as a result of human activity in concentrations that create nuisance growths of aquatic weeds and algae.

Neither the U.S. Senate nor the Canadian Legislature ratified the agreement, which was instead approved under authority of the Boundary Waters Treaty of 1909 (which had created the IJC). This inevitably led to ambiguity concerning the Agreement’s enforceability, especially with regard to funding the programs it recommended. For example, the below “shall” statements included in the Implementation section of Article X.1 and 2(a) were not backed up by any enforceable consequences, with predictable results.

1. The obligations undertaken in this Agreement shall be subject to the appropriation of funds in accordance with the constitutional procedures of the Parties.

2. The Parties shall commit themselves to seek:
   (a) The appropriation of the funds required to implement this Agreement, including the funds needed to develop and implement the programs and other measures provided for in Article V [Programs and Other Measures], and the funds required by the International Joint Commission to carry out its responsibilities effectively.

Eric Rasmussen in a Boston Law College review² observed that the 1972 Agreement ran into difficulties almost as soon as it went into effect:

The pact proposed specific water quality programs and measures but did not include financial assistance provisions for their implementation…Development of the proposed programs and measures for Great Lakes water quality control was not required until December 31, 1975, thereby delaying positive action for three years from the date of signing…Finally, the 1972 Agreement was most disappointing in its failure to broaden the role and responsibilities of the IJC…the power [for the IJC] to implement and enforce the terms of the 1972 pact [was] expressly rejected by both parties.

The Agreement, however, did require that after five years the parties would “review the operation and effectiveness” of the GLWQA, giving researchers, managers, environmental activists and politicians the opportunity to respond to new findings and developing issues.

*Article X established a system for periodic reviews, amendments and expansion of the Agreement.
The Great Lakes Water Quality Agreement of 1978 superseded and replaced the original Agreement of 1972. While the focus of the 1972 Agreement was on controlling polluting chemicals entering the lake, the 1978 GLWQA took an ecosystem approach to water quality issues as illustrated in the Purpose section, Article II, which committed the two countries “To restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem.” That statement was widely understood as a philosophical reorientation from 1972’s goal of improving Great Lakes waters through pollution controls, to 1978’s restoring the Lakes’ ecological integrity to something like their pre-human impact condition.

Based on research compiled by the IJC, the 1978 GLWQA created Annex 3, Control of Phosphorus with the stated purpose of minimizing eutrophication problems and preventing degradation with regard to phosphorus in the Great Lakes System. It’s stated goals were:

(a) Restoration of year-round aerobic conditions in the bottom waters of the Central Basin of Lake Erie;

(b) Substantial reduction in the present levels of algal biomass to a level below that of a nuisance condition in Lake Erie;

(c) Reduction in present levels of algal biomass to below that of a nuisance condition in Lake Ontario including the International Section of the St. Lawrence River;

(d) Maintenance of the oligotrophic state and relative algal biomass of Lakes Superior and Huron;

(e) Substantial elimination of algal nuisance growths in Lake Michigan to restore it to oligotrophic state; and

(f) The elimination of algal nuisance in bays and in other areas wherever they occur.

In addition to reaffirming 1972’s objective of limiting phosphorus in Lake Erie watershed sewage treatment plant effluents to 1.0 mg/L, Annex 3 established phosphorus loads for the base year of 1976 along with recommended future phosphorus loads:

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*In a candid appraisal of the original Agreement, Article IV admitted that “due to both human and natural processes, the objectives of the previous GLWQA were not being met.
†The IJC has been tasked with periodically reviewing GLWQA’s progress and advising on possible modifications.
The phosphorus loads entering the lake listed in the above table addressed total phosphorus (TP), i.e., all forms of phosphorus. It is important to remember that TP consists of forms that readily dissolve in water and forms that do not. The type of dissolved phosphorus most often measured is dissolved reactive phosphorus (DRP) and forms that don’t dissolve are collectively referred to as particulate phosphorus (PP).

The Amendments of 1983 added a Phosphorus Load Reduction Supplement section to Annex 3 of the 1978 GLWQA. Among its modifications were:

- Elimination of target loads for the upper Great Lakes, replacing them with the statement that, “Load reductions for the Upper Lakes will be accomplished by achieving the 1 mg/L phosphorus effluent concentration (on a monthly average) at municipal waste treatment facilities discharging more than one million gallons per day.”

- Addition of further reductions in phosphorus loadings for the lower Great Lakes as indicated in the table below:

<table>
<thead>
<tr>
<th>Baseline</th>
<th>1976 Phosphorus Load in Metric Tonnes</th>
<th>Future Phosphorus Load in Metric Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Superior</td>
<td>3600</td>
<td>3400*</td>
</tr>
<tr>
<td>Lake Michigan</td>
<td>6700</td>
<td>5600*</td>
</tr>
<tr>
<td>Main Lake Huron</td>
<td>3000</td>
<td>2800</td>
</tr>
<tr>
<td>Georgian Bay</td>
<td>630</td>
<td>600*</td>
</tr>
<tr>
<td>North Channel</td>
<td>550</td>
<td>520*</td>
</tr>
<tr>
<td>Saginaw Bay</td>
<td>870</td>
<td>440*</td>
</tr>
<tr>
<td>Lake Erie</td>
<td>20000</td>
<td>11000**</td>
</tr>
<tr>
<td>Lake Ontario</td>
<td>11000</td>
<td>7000**</td>
</tr>
</tbody>
</table>

* These loadings would result if all municipal plants over one million gallons per day achieved an effluent of 1 milligram per litre of phosphorus.

** These loadings are required to meet the goals stated in paragraph 1 above.

The Lake Erie TP target load of 11,000 metric tons per annum (MTA) was first met in 1981 and was exceeded only 8 times through 2011. During those 30 years, the average annual loading was 9,491 MTA, with nonpoint sources accounting for 67%, point sources 23%, and the balance from atmospheric and Lake Huron inputs. The successful attainment of the 11,000 MTA target

*Years with loads exceeding the target experienced large amounts of rainfall and associated nonpoint loads.
in the 1980s represented a reduction of 60% in TP from pre-GLWQA loads of about 28,000 MTA in 1968. However, efforts to achieve the additional reduction of 2,000 MTA for Lake Erie recommended in the 1983 Amendments (in recognition of the need to focus on nonpoint sources of phosphorus loading) fell well short of the mark.

During the 1970s, most of the attention in the U.S. and Canada had been on phosphorus removal programs aimed at municipal and industrial point sources. Since the phosphorus in sewage and other point sources consisted primarily of DRP, a 60% reduction in TP from these sources translated into steep reductions in DRPs entering Lake Erie. DRP is almost entirely bioavailable (readily usable by plants, algae and cyanobacteria), and between 1970 and the mid-1980s, phytoplankton biomass decreased 52-89% in all three basins and walleye fishing and the tourism industry in the eight counties bordering Lake Erie boomed.\(^5\)

Unlike the partial review leading to the 1983 Amendments, the 1987 Protocol Amending of the GLWQA followed upon a full renegotiation of the entire Agreement. The revised GLWQA created the Binational Executive Committee, which replaced the Water Quality Board (created along with the Research Advisory Board in 1972 to assist the IJC in its research responsibilities). It also revised Annex 2, creating a system of Lakewide Management Plans (LAMPs) involving “local governments and other stakeholders” in addressing water quality problem sites called Areas of Concern in the Lakes (AOCs). Within each LAMP and AOC, local agencies were required to create Remedial Action Plans (RAPs) outlining plans for mitigating identified problems.\(^6\)

As indicated in Figure 1,\(^7\) following the signing of the 1987 Agreement, 43 sites were identified as AOCs—12 in Canada, 26 in the U.S. and in five binational sites shared by the two countries. As of this writing, Binational.net\(^8\) indicates that “significant progress” has been made in all AOCs. Seven AOCs have been designated as “delisted” with all beneficial uses restored and an additional two sites are listed as “AOCs in recovery,” meaning that all remedial actions are complete, and monitoring is underway to track the natural restoration of beneficial uses.
At the close of the 1980s, it was widely believed that many of the Great Lakes’ worst water quality problems were being satisfactorily addressed and Lake Erie’s recovery, in particular, seemed to many a showcase for effective environmental management. However, beginning in the mid-1990s, Lake Erie once again started to see signs of eutrophication, with increases in cyanobacteria blooms in the western basin, benthic algae growth in the eastern basin (especially *Cladophora*), and hypoxic conditions in the central basin.\(^9\) It might have been expected that with total phosphorus loadings remaining fairly constant and nonpoint sources of phosphorus overtaking point sources in tributaries to the western and central basins, that particulate phosphorus (in forms bound to soil particles) would comprise an increasing percentage of total phosphorus. However, NCWQR data\(^10\) in Figure 2 for the Maumee River, Sandusky River, Honey Creek and Rock Creek for 1995-2012 indicates otherwise. Instead, the DRP portion of TP had more than doubled from a mean of 11% in the 1990s to 24% in the 2000s.
Variation in TP loads from 1974-2007 proved to be correlated with rates of water discharge but did not display a significant temporal trend over the entire period, although they did increase sharply after the 1990s. That pattern and the increasing proportion of TP exported as DRP were found to reflect changes in agricultural practices and increases in rainfall-related runoff events.

Previous versions of the Agreement required the IJC to prepare biennial progress reports on GLWQA objectives. Although the Commission recognized that progress on achieving the Agreement’s goals was slowing, throughout the decade following the 1987 Protocol, the IJC only recommended the two countries recommit to addressing those goals. In 1998, however, the IJC concluded that many of the Annexes no longer reflected current scientific understanding of the Great Lakes’ problems and that the language in some sections of the 1987 Agreement would benefit from a rewrite. Nonetheless, in 2000, both the US EPA and Environment Canada chose to not enter into a new round of negotiations.11

As the 2000s advanced, public displeasure over the worsening conditions in a variety of areas, but especially with regard to Lake Erie, could no longer be set aside and the 2004 biennial review triggered an in-depth overview (2006-2007), which led the Agreement Review Committee to conclude the GLWQA had become outdated and revisions were needed to address evolving issues associated with re-eutrophication, invasive species,
urbanization and climate change. The first formal renegotiation meetings were held in January 2010 between senior officials from Environment Canada, Foreign Affairs and International Trade Canada, the U.S. Department of State and the U.S. Environmental Protection Agency.

The resulting Great Lakes Water Quality Agreement of 2012\(^\text{12}\) was signed on September 7. It is an amending protocol updating the 1987 Agreement that, while reaffirming the two countries’ commitment to achieving “the goals and objectives of the 1978 Agreement” also “recognized the need to update and strengthen the 1978 Agreement to address current impacts on the quality of the Waters of the Great Lakes and anticipate and prevent emerging threats to the quality of the Waters of the Great Lakes.”\(^\text{13}\) As underscored in the Appendix to the Preamble, it strongly reaffirmed the 1978 Agreement’s emphasis on taking an ecosystem-wide approach to enhancing the Great Lakes’ water quality by:

Recognizing that restoration and enhancement of the Waters of the Great Lakes cannot be achieved by addressing individual threats in isolation, but rather depend upon the application of an ecosystem approach to the management of water quality that addresses individually and cumulatively all sources of stress to the Great Lakes Basin Ecosystem;

A long-time point of controversy concerning public involvement in the GLWQA review and modification process was also addressed in the Preamble by:

Recognizing that, while the Parties are responsible for decision-making under this Agreement, the involvement and participation of State and Provincial Governments, Tribal Governments, First Nations, Métis, Municipal Governments, watershed management agencies, local public agencies, and the Public are essential to achieve the objectives of this Agreement

Although the U.S. EPA has stated that both nations sought out and utilized stakeholder input during the negotiations leading to the new GLWQA, and that the Agreement contains provisions for public participation and notification by the IJC, a number of environmental organizations have voiced disappointment in their perception of minimal public participation in consequential discussions on revising the Agreement.\(^\text{14}\) In fact, the IJC was itself not a direct participant in the three-year negotiations leading to the 2012 Agreement, although it had been asked to comment on draft language on several occasions.\(^\text{15}\)

The research and environmental outreach programs of the National Center for Water Quality Research are most directly affected by sections of the GLWQA that concern the

management of pollutants in Lake Erie, and therefore especially with the 2012 Agreement’s Annex 4, which addresses HNAB-causing phosphorus loading into the Lake. However, it is also useful to view the Agreement’s directives on nutrient management within the larger context of its recommendations on other topics of Great Lakes concern. Chris Fryefield’s 2013 Master’s Thesis (written for his Doctor of Jurisprudence degree) reviewed the evolution of the 2012 GLWQA.\(^\text{16}\) His summary of the Agreement’s updated ten Annexes is presented below.
<table>
<thead>
<tr>
<th>Annexes of the 2012 GLWQA</th>
<th>Purpose</th>
<th>Key Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annex 1 Areas of Concern</td>
<td>Restoration of impaired beneficial uses in AOCs with Remedial Action Plans</td>
<td>Used to be part of former Annex 2 with LAMPs</td>
</tr>
<tr>
<td>Annex 2 Lakewide Management</td>
<td>Establishment of Lake Ecosystem Objectives (LEOs) to assess water quality and ecosystem health for Lake as a whole. Also calls for integrated nearshore framework. Lakewide Action Management Plans (LAMPs) for each Lake and associated rivers</td>
<td>Keeps and expands LAMPs, similar language to former Annex 2 LEOs kept and expanded from former Annex 1 Supplement</td>
</tr>
<tr>
<td>Annex 3 Chemicals of Mutual Concern</td>
<td>Attainment of General and Specific Objectives for water quality by coordinated control of chemicals of mutual concern. References domestic water quality programs by Parties.</td>
<td>Language much broader than former Annex text. No longer contains appended list of substances.</td>
</tr>
<tr>
<td>Annex 4 Nutrients</td>
<td>Manage phosphorus (and other nutrients if warranted) concentrations and loadings. Reduction of nutrient loading to prevent HABs causing hypoxia, nuisance toxins, eutrophic status. Parties to monitor and consult on efficacy.</td>
<td>Similar substance objectives to those of the 1983 Supplement in former Annex 3. Keeps phosphorus load target lists, no longer has allocations by country.</td>
</tr>
<tr>
<td>Annex 5 Discharges from Vessels</td>
<td>Preventing and controlling vessel discharges, including oil and hazardous polluting substances, garbage, wastewater and sewage, biofouling (invasives and pathogens) and ballast water.</td>
<td>Contains language from former Annexes 4, 5 and 6. New language on biofouling and ballast water recognizes pathway for invasions.</td>
</tr>
<tr>
<td>Annex 6 Aquatic invasive species (AIS)</td>
<td>Binational strategy to prevent introduction of AIS, control or reduce spread of existing AIS, attempts to eradicate where feasible. Notes uncertain nature of future invasions and need for risk assessments and new controls.</td>
<td>This annex is new. Mentions potential impact of climate change on AIS vectors (Subsection C [7]).</td>
</tr>
<tr>
<td>Annex 7 Habitat and Species</td>
<td>Maintaining and protecting native species and their habitat. Calls for &quot;baseline survey of existing habitat&quot; to measure gains and losses. Notes LAMPs as principal mechanism for coordinating conservation efforts. Includes definition of ecosystem service</td>
<td>This Annex is new. Links native species and habitat to ecosystem approach and ecosystem services.</td>
</tr>
<tr>
<td>Annex 8 Groundwater</td>
<td>Improvement of &quot;groundwater science&quot; by Parties. Calls for management, protection, and remediation of groundwater quality.</td>
<td>Focus shift from former Annex 16 - groundwater to be managed for itself as well as for potential effect on Lakes</td>
</tr>
<tr>
<td>Annex 9 Climate Change</td>
<td>Calls Parties to coordinate on identifying, understanding, and predicting climate change</td>
<td>This Annex is new. Focus is on ultimate effects of climate</td>
</tr>
</tbody>
</table>
Impacts on water quality of Lakes. Parties should coordinate water quality actions with water quantity actions taken by IJC as climate change links both.

change on Great Lakes, with no language about mitigation or greenhouse gases.

Annex 10

Science

Parties to improve science (modeling, observation, research, etc.) and improve coordination on scientific development. Facilitation of information sharing and comprehensive knowledge.

Similar to former Annex 17. Language on incorporation of traditional knowledge is new.

Section C of Annex 4 (Nutrients: Substance Objectives) presented a series of statements on specific phosphorus nutrient loading targets that had yet to be developed:

To achieve Lake Ecosystem Objectives, the Parties deem it essential to establish Substance Objectives, in accordance with Article 3(1)(b)(ii), for phosphorus concentrations for the open waters and nearshore areas of each Great Lake. To achieve these Substance Objectives for phosphorus concentrations, the Parties shall develop phosphorus loading targets and allocations for each Party for each Great Lake, as required.

In establishing Substance Objectives for phosphorus concentrations and phosphorus loading targets, the Parties shall take into account the bioavailability of various forms of phosphorus, related productivity, seasonality, fisheries productivity requirements, climate change, invasive species, and other factors, such as downstream impacts, as necessary.

The Parties shall complete this work for Lake Erie within three years of entry into force of this Agreement and complete this work for the other Great Lakes on a schedule to be determined by the Parties.

The Parties shall periodically review the Substance Objectives for phosphorus concentrations, phosphorus loading targets, and phosphorus loading allocations, apportioned by country to ensure that Lake Ecosystem Objectives are met.

As prescribed in Annex 4, the process for establishing phosphorus target loads for Lake Erie was largely completed three years after the 2012 Agreement went into effect. Following meetings in 2007 and 2013, the Ohio Phosphorus Task Force (which Dave Baker had played a key role in organizing) recommended a 40% reduction in phosphorus loading from the Maumee and other tributaries to Lake Erie’s Western Basin. In October of 2013, the IJC endorsed the Task Force’s recommendation and called for similar reductions for the Central Basin.

In May 2015, the Objectives and Targets Task Team organized under Annex 4 issued its final report calling for a 40% reduction in total phosphorus and dissolved reactive phosphorus loads entering the Western Basin* from that observed in the baseline spring (May 1-July 31) of 2008.

*From Canada’s Thames River and Leamington tributaries; and Ohio’s Maumee, Portage, Sandusky, Huron Rivers and Toussaint Creek and Michigan’s River Raisin. Such a reduction would amount to some 3,000 MTA from 2008.
2008, and a 40% reduction in TP loading to the Central Basin. The Task Team chose 2008 as the base year for comparisons because it was a relatively wet year and the Maumee’s spring discharge had only been exceeded two times during the preceding 20 years. The proposed reductions, it was hypothesized, would diminish the size and extent of HNABs in the Western Basin to less than those observed in 2004 and 2012* in nine of ten years, and raise the dissolved oxygen concentration in the Central Basin to over 2 mg/L. The U.S. and Canadian governments approved the recommend target goals in February 2016.

If met, the TP loading goal for the Maumee River would result in a maximum loading of 860 metric tons per annum (MTA) corresponding to a Flow-weighted mean concentration (FWMC) of 0.23 mg/L while the DRP goal for the Maumee would allow a maximum of 186 MTA, corresponding to a FWMC of 0.05 mg/L. It was felt that if phosphorus loading were to be so reduced, the Western Basin’s recovery from HNABs would likely be fairly rapid since retention time for the shallow basin’s water is only 20-50 days (and 2.7 years for the entire lake). This point is illustrated in the Figure 3 based on NCWQR data.17

Figure 3. Western basin bloom severity (bars) and relative spring discharge and loads of various forms of phosphorus (points) expressed as percentages of average 2002–2016 values. (Load and discharge data from the Maumee River, 2002 to 2018.)

The years 2011 and 2015 each experienced intense late-summer HNABs in the Western Basin preceded by heavy spring discharge from the Maumee River. The fact that in both instances the Western Basin’s waters shifted from high phosphorus loads with extensive cyanobacteria blooms to much lower levels of each in the space of one year is indicative of the potential for the Basin’s rapid recovery under appropriate conditions.

With the formal adoption of phosphorus target loads for the western and central basins of Lake Erie, stakeholders naturally wondered how efforts to achieve the targets would be implemented, how progress toward achieving the targets would be monitored and evaluated, and

*These two years experienced the lowest discharge rates for the Maumee River during the 12-year period between 2002-2013 and the 5th and 6th least severe HNABs.
how open to public input the process leading to possible future modifications might be. Before considering such implementation issues, an interesting question pertains to the enforceability of the GLWQA’s precepts. That is, from a legal standpoint, does the Agreement constitute an essentially non-binding “soft law”? In international law, soft law is a voluntary arrangement between countries without agreed-upon deadlines and mechanisms for enforcement. Fryefield observes:\textsuperscript{18}

Generally, these nonbinding agreements are written with language that expresses broad principles and general intentions but lack specific goals and mechanisms for achievement…For example, the language in Articles 3 and 4 of the 2012 Agreement reference the Parties “best efforts” to achieve the non-specific goals they have agreed on.

The Purpose [section] of the 2012 Agreement, like its predecessor Agreement of 1978, hedges with the language “the Parties agree to maximize their efforts to: (c) eliminate or reduce, to the maximum extent practicable, environmental threats to the Waters of the Great Lakes”. This language makes the tone of the Agreement sound even less binding – the Parties agree to do as much as is practicable to the extent they can.

Such a soft law agreement could still induce the parties to take action towards the general goals, but failure to do so would probably not cause the other party or parties to take action against the nation in non-compliance…The Great Lakes is a two party commons, in this sense, with no higher regulatory authority in place to force either country to act against its own interests for the other, or for the good of the Lakes as an ecosystem.\textsuperscript{*}

That said, since 2012 both Canada and the U.S. have moved forward on addressing the Key Commitments listed under Annex 4 which were:

- By 2016, develop binational substance objectives for phosphorus concentrations, loading targets, and loading allocations for Lake Erie;
- By 2018, develop binational phosphorus reduction strategies and domestic action plans to meet the objectives for phosphorus concentrations and loading targets in Lake Erie;
- Assess, develop, and implement programs to reduce phosphorus loadings from urban, rural, industrial and agricultural sources. This will include proven best management practices, along with new approaches and technologies;
- Identify priority watersheds that contribute significantly to local algae development, and develop and implement management plans to achieve phosphorus load reduction targets and controls; and
- Undertake and share research, monitoring and modeling necessary to establish, report on and assess the management of phosphorus and other nutrients and improve the understanding of relevant issues associated with nutrients and excessive algal blooms.

In the U.S., Domestic Action Plans (DAPs) required for Ohio, Michigan, Indiana and

\textsuperscript{*}Fryefield’s comment here may be too forceful. For example, Title I of the Great Lakes Critical Programs Act of 1990 amended the CWA by requiring Great Lakes states to adopt water quality standards, anti-degradation policies, and implementation procedures adhering to EPA-set guidelines consistent with several parts of the 1978 GLWQA, https://www.congress.gov/bill/101st-congress/house-bill/4323
Pennsylvania were finalized in February 2018 as was the overall U.S. Action Plan for Lake Erie, which outlines federal and state efforts to achieve the binational phosphorus load reduction targets. The U.S. Action Plan’s primary goals are to:

- Clearly articulate federal and state commitments.
- Identify potential policy/program needs.
- Provide focus for allocation of resources.
- Establish accountability for actions and results.
- Provide a consistent framework across the Lake Erie basin for implementing programs and monitoring success.

Figures 4-8, taken from the Phosphorus Reduction Goals and Priority Watersheds section of the U.S. Plan for Lake Erie, illustrate the principal environmental challenges facing the Lake’s three basins and current tributary phosphorus loadings associated with these problems.

Figure 4. Principal areas of late-summer HNAB and hypoxia in Lake Erie.
The principal phosphorus-related issues the Plan is attempting to address are:

- In the western basin: cyanobacteria blooms and associated toxins
- In the central basin: seasonal hypoxia
- In the eastern basin: excessive growth of nuisance algae, primarily *Cladophora*, on lake bottom

Most of the total annual phosphorus load to the Lake is delivered from the Maumee, Detroit, and Sandusky Rivers in the U.S. and the Thames and Grand Rivers in Ontario. The Plan notes that “On average, runoff from nonpoint sources are estimated to be responsible for about 72 percent of the total phosphorus load entering Lake Erie each year; in the western basin, nonpoint sources are estimated to contribute upwards of 89 percent of the annual total phosphorus load in that portion of the lake’s tributaries.” As such, the Plan has developed different phosphorus management regimes for each basin:
In summarizing the main components of the U.S. Action Plan for Lake Erie, an EPA-produced Factsheet\textsuperscript{21} stated that implementation of the Plan’s objectives will involve “collaboration among 5 federal agencies, 5 states, and numerous external non-government industry and academic partners.” It went on to indicate that “Federal partners will continue to support states with financial and technical assistance as they work with their local agricultural community, watershed protection groups, water utilities, landowners, and municipalities to develop nutrient reduction strategies tailored to their unique set of challenges and opportunities.”
Granting that accurate predictions of future conditions in Lake Erie are difficult to generate given the number of influencing factors at play—from rates of farmer adoption of best management practices to the frequency of large rainfall events—architects of the Plan suggest the Lake could see a reduction in TP loading of around 2.4 million pounds (from 2008 levels) by 2020, which would amount to 34% of the reduction needed. Achieving the full reduction of 7.3 million pounds by the Plan’s proposed 2025 deadline would therefore prove challenging. Figure 9 (from the Factsheet) depicts how one model suggests Western Basin HNABs observed during 2003-2017 would have been reduced had there been 40% less phosphorus loading than was actually observed. Even with such reductions, 2011 and 2015 HNABs in the Western Basin would have exceeded target blooms.

Finally, two significant, interrelated modifications incorporated into the 2012 GLWQA include its embrace of the Adaptive Management model for addressing its objectives, and the inclusion of more fully developed opportunities for public engagement in this process. The U.S. Plan for Lake Erie defines adaptive management as “a long term, structured and iterative process for continually improving management results by learning from the outcomes of previous policies and practices.” The Plan’s authors argue that “This approach is necessary because natural systems are inherently variable, and the impacts of management actions are difficult to predict accurately. Uncertainty is made even greater with a changing climate and ecosystem changes caused by invasive species.” The Plan illustrates the process with a graphic (depicted in Figure 10) developed by the Delta Stewardship Council of Sacramento CA of the 9-step Adaptive Management Cycle22.
In the case of the Lake Erie Domestic Action Plan, adaptive management entails that each of the following questions be addressed, and re-addressed, every year:

- What progress has been made implementing the DAPs?
- What are the changes in water quality?
- What are we learning about factors affecting water quality changes to better implement practices?
- What refinements are needed in monitoring and modeling approaches to better assess trends?
- Do we need to update our models in response to better understanding other ecosystem drivers (e.g. implications of climate variability, legacy phosphorus, invasive mussels, etc.)?
- Do we need to change our programs or policies to minimize obstacles or accelerate progress towards achieving the Lake Erie Objectives?
In the past, GLWQA negotiations were commonly conducted behind closed doors, with many individuals, organizations and businesses only learning of decisions affecting them after-the-fact. Recognizing the negative impact of such secrecy on stakeholder buy-in, Canada and the U.S. both sought participation of a wide variety of interested parties in the 2017 development of DAPs through numerous meetings with targeted stakeholder groups. Under the 2012 GLWQA, the IJC is tasked with evaluating each government’s progress and with providing stakeholder feedback to agencies implementing the Agreement. The two countries are also required to convene a Great Lakes Public Forum once every three years to discuss the state of the Lakes and progress being made under the Agreement. A central function of the Forum is to provide an opportunity for public input. Subsequently, a progress report on implementation is issued, which also includes Science and Action Priorities for the next three years. Following the 2016 Forum, the countries agreed on the following Annex 4 Science and Action priorities to guide their work for 2017-2019.  

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<tr>
<td>Develop and implement monitoring and modeling activities within an adaptive management framework to support tracking and reporting on progress towards achievement binational phosphorus load reduction targets for Lake Erie. Efforts will include establishing and coordinating comparable monitoring techniques in tributaries and in the Lake and improving knowledge on approaches for reducing phosphorus loads from the watershed to Lake Erie.</td>
<td>Engage all levels of government, stakeholders, Tribes, First Nations and Métis communities in the development of Domestic Action Plans for the reduction of phosphorus loadings to Lake Erie.</td>
</tr>
<tr>
<td>Research, monitoring and modeling activities to support the assessment and future actions to address algae problems in Lakes Ontario, Huron and Michigan. Will include addressing gaps in our knowledge of nutrient dynamics in these lakes to better understand the distribution and movement of nutrients between nearshore and offshore zones, and the influence of climate change on nutrient inputs or ecosystem response.</td>
<td>Implement Domestic Action Plans</td>
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<tr>
<td>Establish phosphorus load reduction targets for the eastern basin of Lake Erie.</td>
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</table>

At this writing, the summary report for the Great Lakes Public Forum held in Milwaukee, WI on June 17-19, 2019 had not been disseminated. In addition to discussions centered on establishing Science and Action Priorities for each Annex for the next three years, the Forum had also been scheduled to address:

- Lakewide Management
- Areas of Concern
• Nutrients
• Invasive Species
• Habitat Restoration
• Chemicals of Mutual Concern; and
• Discharges from Vessels

1 Agreement on Great Lakes Water Quality (with annexes and attachments). Signed at Ottawa on 15 April 1972.
8 Binational.net is a collaboration between the U.S. EPA and Environment and Climate Change Canada providing information on work undertaken by the two governments in support of the GLWQA.
https://binational.net/wp-content/uploads/2014/05/1094_Canada-USA-GLWQA-_e.pdf
13 Preamble to the GLWQA of 2012.
16 Ibid.


Appendix D. NCWQR Bibliography:

Publications by the Laboratory’s Researchers, 1971-2019

This Appendix includes journal articles, books, book chapters and reports but does not include presentations given at conferences or before other groups, except as published in a Proceedings format. Surnames of the Laboratory’s professional staff members are boldfaced.

2019


2018


2017


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2002

2001

2000
Agrochemical Fate and Movement: Perspective and Scale of Study. American Chemical Society, Washington, DC.


1999


1998


1997


1995


Richards, R.P. 1995. (Software). An automated, best-stratification seeking algorithm for estimating pollutant loads using the Beale Ratio Estimator. (FORTRAN77 software for Macintosh which iteratively solves the problem of optimal stratification of concentration/flow data during load calculation, and provides graphic displays of its progress, developed under a grant to U.S. EPA.)


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**1988**


**1987**


**1986**


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Appendix E. NCWQR Bibliography:

Publications by Senior Researchers Baker, Richards, Krieger, Confessor and Johnson

This Appendix includes publications listed on the curriculum vitae of David B. Baker, R.P. Richards, K.A. Krieger, Remegio B. Confesor, Jr. and Laura T. Johnson arranged by date from most recent to the earliest year of employment at Heidelberg. It does not include presentations given at conferences or before other groups, except as published in a Proceedings format.

David B. Baker

Journal Articles and Reports:


(www.riverwatershed.org)


Reference Group on Great Lakes Pollution from Land Use Activities. International Joint Commission, Windsor, Ontario


R.P. Richards

Journal Articles:


212


E-publications:

Books and Book Chapters:


Proceedings:


Significant Reports:


Other Publications:


Richards, R.P. (1995, Software). An automated, best-stratification seeking algorithm for estimating pollutant loads using the Beale Ratio Estimator. (FORTRAN77 software for Macintosh which iteratively solves the problem of optimal stratification of concentration/flow data during load calculation, and provides graphic displays of its progress, developed under a grant to U.S. EPA.)
K.A. Krieger

Journal Articles:


Proceedings, Technical Reports, Book Reviews, and Newsletter Articles


**Remegio B. Confesor, Jr.**

**Journal Articles:**


Book Chapter:


Project Report:


Laura T. Johnson

Journal Articles:


Quantifying the production of dissolved organic nitrogen in headwater streams using $^{15}$N tracer additions. Limnology and Oceanography 58: 1271-1285.


Appendix F: List of Acronyms

ACCE. Academic Comprehensive Campaign for Excellence.
APEX. Agricultural Policy Enviromental eXtender.
ARS. Agricultural Research Service of the USDA.
A-STP. Agronomic Soil Test Phosphorus.
ASIIP. Academic Strategic Initiative and Implementation Plan.
BAPP. Bioavailable particulate phosphorus.
BMP. Best Management Practices.
CCA. Certified Crop Advisor.
C3S. Copernicus Climate Change Service.
CLWS. Curriculum-based, Long-term Watershed Studies model for environmental education.
CPI. Center for Public Integrity.
CREP. Ohio Lake Erie Conservation Reserve Enhancement Program.
CRP. Conservation Reserve Program.
CWA. Clean Water Act, more formally the FWPCA Amendments of 1972.
CWTP. Heidelberg’s Cooperative Well Testing Program.
DO. Dissolved oxygen.
DRP. Dissolved Reactive Phosphorus. Identical to SRP.
ECMWF. European Centre for Medium-Range Weather Forecasts.
ECOFOR. Ecological forecasting.
EERC. The Edison Environmental Research Center, a proposed watershed studies research facility to be housed at Heidelberg University.
EQIP. Environmental Quality Incentives Program.
E-STP. Environmental Soil Test Phosphorus.
EWG. The Environmental Working Group.
FWMC. Flow-weighted Mean Concentration.
FWPCA. Federal Water Pollution Control Act (1948), the predecessor to the Clean Water Act.
FWPCA. Federal Water Pollution Control Administration, created under the FWPC.
GCM. Global Circulation Model.
GLERL. Great Lakes Environmental Research Laboratory, located in Ann Arbor MI.

GLSM. Grand Lake Saint Marys.

GLWQA. Great Lakes Water Quality Agreement.

GPP. Gross Primary Productivity.

HTLP. Heidelberg Tributary Loading Program.

IBI. Index of Biotic Integrity.

ICI. Invertebrate Community Index.

IJC. International Joint Commission.

IPNI. International Plant Nutrition Institute.

LEAP. Lake Erie Agro-Ecosystem Program.

LEASEQ. Lake Erie Agricultural Systems for Environmental Quality.

LEEF. Lake Erie Education Fund.

LEPF. Lake Erie Protection Fund.

LEWMS. Lake Erie Wastewater Management Study.

LHA. Lifetime Health Advisory.

LTAR. Long-term Agro-ecosystem Research program.

MCL. Maximum Contaminant Level.

MNM. ODNR’s Manure Nutrient Management program.

NCCOS. NASA’s National Centers for Coastal Ocean Science.

NCWQR National Center for Water Quality Research.

NH₃. Ammonia.

NH₄. Ammonium.

NO₂. Nitrite.

NO₂⁺³. Nitrite + Nitrate.

NO₃. Nitrate.

NOAA. National Oceanic and Atmospheric Administration.

NPDES. National Pollutant Discharge Elimination System.

NPP. Net Primary Production.

NRCS. National Resources Conservation Service.

NSF. National Science Foundation.
NTT. Nutrient Tracking Tool.

ODNR. Ohio Department of Natural Resources.

OEPA. Ohio Environmental Protection Agency.


PSA. Public Sector Advisors.

Q. The symbol representing rate of discharge of water in a tributary.

QC. Quality Control.

QHEI. Qualitative Habitat Evaluation Index.

R-B Index. Richards-Baker Flashiness index

SI. Severity Index.

SRP. Soluble Reactive Phosphorus. Identical to DRP.

SRS. Soluble Reactive Silica.

STP. Soil Test Phosphorus.

SWAT Soil and Water Assessment Tool.

SRWC. Sandusky River Watershed Coalition.

TBAP. Total Bioavailable Phosphorus.

TMDL. Total Maximum Daily Load.

TKN. Total Kjeldahl Nitrogen.

TP. Total Phosphorus.

TSS. Total Suspended Solids

TWMC. Time-weighted Mean Concentration.

USDA. U.S. Department of Agriculture

USEPA. The U.S, Environmental Protection Agency.


VPAA. Vice President for Academic Affairs.

WLEB. Western Lake Erie Basin.

WQL. Water Quality Lab.

WRTDS. Weighted Regressions on Time, Discharge and Season.
Appendix G: Glossary

4R Nutrient Stewardship. A philosophy and program promoting agricultural sustainability developed through collaboration between the scientific community and the fertilizer industry. It defines the four Rs of sound fertilizer management as using the Right Source of fertilizer (matching fertilizer type to crop needs), at the Right Rate (given crop needs), at the Right Time (when needed) at the Right Place (applying them where crops can best make use of them).

4R Nutrient Stewardship Certification Program. A voluntary program providing recognized standards for agricultural retailers and nutrient service providers in the Western Lake Erie Basin. The certification program represents a major effort by the fertilizer industry to promote 4R stewardship among its client farmers within the watershed.

Acute phosphorus loss from a field. Enhanced movement of dissolved phosphorus from fields into neighboring waterways with runoff during storm events occurring before incorporation of phosphorus into the soil.

Algae. A general, non-taxonomic term most commonly applied to aquatic organisms capable of photosynthesis and small enough to float in water. But this is a weak definition and the term does not refer to a single group of closely related organisms. So-called red, brown and green algae, for example, are not members of the same taxonomic group, and blue-green algae (see Cyanobacteria) are more closely related to bacteria than to the eukaryotes (organisms whose cells have a nucleus, among other traits). Adding to the confusion, each of the above-named groups also contains species that form large multicellular forms far too large to float—the various “seaweeds” are sometimes referred to as macroalgae.

Algal bloom. Under appropriate environmental conditions in freshwater ecosystems, various forms of green algae and/or Cyanobacteria can become so abundant that they can become a nuisance or health hazard for aquatic life and possibly humans. HABs (hazardous algal blooms) or HNABs (hazardous and nuisance algal blooms). In recent decades, they are commonly the result of cultural eutrophication.

Agricultural Policy/Environmental eXtender (APEX). A USDA model developed for managing whole farms or small watersheds to obtain maximum production efficiency and maintain environmental quality. APEX has components for routing water, sediment, nutrients, and pesticides across complex landscapes and channel systems to the watershed outlet as well as groundwater and reservoir components. APEX is the main driver of the Nutrient Tracking Tool (NTT) model.

Agricultural Research Service (ARS). The principal research arm of the USDA, it is charged with extending the nation's scientific knowledge and solving agricultural problems through its four national program areas: nutrition, food safety and quality; animal production and protection; natural resources and sustainable agricultural systems; and crop production and protection. ARS is divided into 5 geographic areas: Midwest, Northeast, Pacific West, Plains, and Southeast.
Apoxia (Apoxic waters). Waters that have no dissolved oxygen.

Basin, Drainage basin. See Watershed.

Benthic, benthos. Benthic is an adjective referring to the bottom of a water body, whether ocean, river or stream. Benthos refers to the community of organisms that live in the benthic zone.

Biochemical Oxygen Demand [BOD]

Broadcast fertilization. A method by which fertilizer is applied on the surface across an entire field. High capacity fertilizer spreaders typically spin dry fertilizer or spray liquid fertilizer on the soil surface or on a growing crop. When used in combination with conservation tillage over a period of years it leads to high levels of phosphorus stratification.

Chemograph. A graph depicting changes in the concentration of a compound observed in a body of water over time.

Chronic phosphorus loss from a field. Loss of phosphorus over long periods of time through it occurs through seepage through macropores and inter-soil particle spaces into groundwater and tiling systems, and with non-storm related surface movement of water.

Clean Water Act (CWA). The primary federal law governing water quality issues. Its official name is the Federal Water Pollution Control Act Amendments. The FWPCA was enacted in 1948 but the 1972 Amendments completely revised the law and ever since it has more commonly been referred to as the Clean Water Act.

Concentration exceedency curve. A graph depicting the percentage of time a given concentration of a pollutant was exceeded during a period of observation.

Concentration. The amount of material (a nutrient, sediment, herbicide, etc.) being carried within a unit volume of water, commonly measured as mass per liter of water passing a sampling station—averaged over a given time unit, such as a day.

Conservation Reserve Enhancement Program (CREP). An offshoot of the CRP, the program uses State funds to supplement Federal funds as an additional incentive to farmers to preserve land that has been identified as posing special environmental concerns.

Conservation Reserve Program CRP). A cost-sharing program of the USDA under which the government pays a farmer to take certain highly erodible croplands out of production and convert them to a cover crop for a set number of years. The program’s intention is to reduce land erosion, improve water quality, and benefit wildlife.

Conservation tillage. As a general rule of thumb, conservation tillage is a method of preparing a field for seeding that leaves at least 30% of crop residue on the soil surface. Its advantages over conventional tillage include reducing soil erosion, improving soil health, reducing soil compaction with heavy equipment and reducing fuel and labor costs.
• No-till. A cultivation method that requires no actual tilling of land.

• Strip tillage. A cultivation method where only thin strips are cultivated where seeds will be planted. The strips are located where the rows of crops are located. Each year, the strips will shift roughly six inches in one direction.

• Mulch-tillage. A cultivation method that does till the soil before planting but does not invert the soil. It mixes crop residue with the soil while leaving some amount of residue on the surface leaving it rough and cloddy.

• Ridge tillage. A cultivation method that uses special machinery to form the soil into ridges into which seeds are then planted.

Conventional or Intensive tillage. A cultivation method that leaves less than 15% residue on the soil. It commonly involves inversion tillage, turning surface layer of soil upside-down.

Cyanobacteria. Sometimes still referred to by the misleading, older name, blue-green algae, the Cyanobacteria are generally considered a specialized group of bacteria that can produce their own energy-rich carbohydrates through photosynthesis. (It’s widely accepted that the chloroplasts that enable plants to perform photosynthesis likely had their ancestry in an ancient cyanobacter.) Under appropriate conditions, many forms excrete a variety of toxins collectively referred to as cyanotoxins. For example, the various species of the genus Microcystis produce a class of cyanotoxins called microcystins, which cause serious damage to the liver.

Data sonde. A machine that automatically collects and records environmental data while placed at a sample location for a period of time. Sonde is French for probe.

Discharge (Q). Rate at which water passes a sampling station on river or stream, measured as volume per time unit, e.g. cubic meters per min, hour or day. Flow is an equivalent term.

Environmental Quality Incentives Program (EQIP). A program that provides cost-sharing, technical and education assistance to farmers with the twin goals of promoting production and environmental quality. Annual disbursement of funds goes 60% to environmental concerns associated with livestock production and the remainder to crop production.

Epilimnion. The top-most layer in a deep thermally-stratified occurring above the thermocline. It is warmer and typically has a higher pH and higher concentration of dissolved oxygen than the hypolimnion, especially during late summer when the mixing of epilimniotic and hyolimniotic waters are at a minimum.

Eutrophication, Cultural Eutrophication, Re-eutrophication. Eutrophication is enrichment of a water body with nutrients (especially phosphorus and nitrogen compounds) important to plant and algae growth. It is a natural process in lakes that occurs as streams or rivers carry nutrients and sediments into the water body. A eutrophic water body will be rich in plant and algae growth, which provides food for all manner of aquatic animal life. However, cultural
eutrophication occurs when human activities accelerate the process (through inefficient sewage treatment, poor land management practices, etc.). This can lead to HNABs. By the end of the 1980s, it seemed that much of the cultural eutrophication problems that had caused massive HNABs in the 1960s and 1970s had been satisfactorily addressed. However during the mid-late 1990s, problems, especially in the lake’s Western and Central Basins, began to reappear due to the re-eutrophication of the Lake that is discussed in this history.

Fecal coliform

Flow. See Discharge.

Flow-weighted Mean Concentration (FWMC). A method of dealing with the fact that, since the Lab samples more frequently during high flow periods than in low, pollutant concentrations are generally higher during high flows. By weighting the concentration observed in a given sample by both its “time-window” (the time between the last sample and the next one) and the rate of flow during that time window, and then dividing the sum of weighted loadings by the total discharge over all time periods, this bias is eliminated. Compare Time-weighted Mean Concentration (FWMC).

FWMC/TWMC ratio. This ratio provides an indication as to whether the concentration of a substance increases or decreases as flow increases. If the ratio > 1.0, its concentration increases with increasing rate of flow.

Great Lakes Water Quality Agreement (GLWQA). First signed in 1972 to coordinate the actions of Canada and the United States in their efforts to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes.

Gross Primary Productivity (GPP). Generally refers to either the total amount of organic matter (biomass) or energy that is synthesized from sunlight and atmospheric or aqueous carbon dioxide by photosynthetic plants, algae and cyanobacteria, although chemosynthetic generation of organic matter and energy is also important in many systems.

Hydrograph. A graph depicting discharge (flow) rates over time.

Hydrology. The science concerned with the properties of earth’s water, especially its movement across and through land.

Hydrologic system. The processes of precipitation, evaporation, transpiration, infiltration, groundwater flow, streamflow that define how water moves across and through the landscape, into and out of the atmosphere, and into and out of surficial and ground waters.

Hypolimnion. The dense, cold bottom layer of water in a deep, thermally-stratified. It is the layer that lies below the thermocline and continuing down to the bottom of the lake.

Hypoxia (Hypoxic waters). Waters that have relatively little dissolved oxygen.

Lifetime Health Advisory (LHA). Recommendation developed by EPA’s Office of Drinking Water for the concentration of a given pollutant that is deemed to pose no significant adverse
health effects when consumed over the course of a lifetime. LHAs, which are not enforceable regulations are the basis on which enforceable MCL regulations are based.

Loads. Loadings. The amount of material (a nutrient, sediment, herbicide, etc.) being carried by a water body in a given unit of time, commonly measured as mass of the given material passing a sampling station per day.

Macropores. Fissures in the soil leading down through the zone of interaction. The release of DRP through macropores into subsurface tiles and offsite receiving waters represents a large component of loss of legacy phosphorus.

Maximum Contaminant Level (MCL). EPA-established regulatory standard for a given pollutant in drinking water by which water treatment plants must abide.

Metric ton. Referred to as a tonne in Europe and metric ton in Canada and the U.S., it is a mass equal to 1,000 kilograms (kg), or about 2,204.6 pounds. In the U.S., a ton weights 2,000 pounds, so a metric ton is about equal to 1.102 tons. (In Europe, the U.S. ton is referred to as a short ton.)

Microgram (µg). One-millionth of a gram. A concentration of 1 microgram of a substance in a liter of water (1 µg/L) is equivalent to 1 part of the substance per billion (1 ppb).

Milligram (mg). One-thousandth of a gram. A concentration of 1 milligram of a substance in a liter of water (1 mg/L) is equivalent to 1 part of the substance per million (1 ppm).

Models. Models are representations of real-world systems or processes. Mathematical models use a series of mathematical equations, ranging in complexity from very simple to highly sophisticated, to summarize current understanding of a system and predict how the system might operate under a given set of conditions.

- Ensemble modeling. Incorporating the predictive results of multiple models of a given real-world system in developing a single predictive value. For example, several models for predicting climatic conditions in a given locality 20 years in the future will produce different predictions although all begin with the same input data because they incorporate different assumptions as to how those data will interact and change over time. Researchers may then report the average expected temperature, summer precipitation, etc. based on those models, along with statistical measures of variability such as standard error.

- Field-scale modeling. Computer-based mathematical modeling that simulates hydrologic processes operating within a given field and how these processes impact off-field hydrologic processes. Field-scale modeling is useful for scientific studies of how different forms of land management at a given location are likely to impact off-site water quality issues. It therefore has strong potential for advising farmers on the best BMPs to adopt for their situation.

- Watershed modeling. Computer-based mathematical modeling that takes a holistic approach to simulating hydrologic processes with a watershed. Watershed-scale modeling has become important as a scientific research and management tool in efforts to understand and control pollution issues in surface waters within a watershed.
Nitrate. A nitrate is a negatively charged (anion) compound consisting of one nitrogen atom and three oxygen atoms, commonly written as $\text{NO}_3^-$ (or, if not indicating its typical charged state, as $\text{NO}_3$).

Nitrite. A nitrate is a negatively charged (anion) compound consisting of one nitrogen atom and two oxygen atoms, commonly written as $\text{NO}_2^-$ (or, if not indicating its typical charged state, as $\text{NO}_2$).

Nonpoint sources of pollution. Pollutants entering a water body from a relatively diffuse area, such as nutrients, soil particles and pesticides carried by storm waters running off a farmed field.

Nutrient Tracking Tool (NTT). A free, online, user-friendly modeling tool that quantitatively estimates the nitrogen, phosphorus and sediment losses from crop and pasture lands. It can be used to estimate potential environmental improvement on farms with adoption of various BMPs. NTT was developed by the Texas Institute of Applied Environmental Research at Tarleton State University with support from USDA's Office of Environmental Markets.

Ohio Working Lands Buffer Program. The program encourages producers in the Western Lake Erie Basin to establish year-round harvestable cover on eligible, typically highly erodible cropland. The intent of the program is to encourage the development of buffers on cropland to filter surface water while allowing participants to harvest forage from established areas.

Phosphate. A phosphate is a negatively charged (anion) compound consisting of one phosphorous atom and four oxygen atoms, commonly written as $\text{PO}_4^{3-}$ (or, if not indicating its typical charged state, as $\text{PO}_4$).

- Organic phosphate. A phosphate attached to a carbon-containing molecule such as is found in the tissues of living organisms or sewage.

- Inorganic phosphate. A phosphate that is not attached to a carbon-containing molecule. There are two forms: orthophosphates and polyphosphates. Plants and algae can only absorb and make use of inorganic phosphates in making the organic phosphates needed by their bodies. When an organism dies (or it excretes waste), organic phosphates are commonly broken down into inorganic phosphates.

- Particulate phosphorus (PP). Organic and inorganic phosphorus may be attached to clay or other particles. Particulate phosphorus may be found suspended in water or embedded in the sediment at the bottom of a water body.

- Orthophosphates are $\text{PO}_4$ molecules not attached to any other atoms. They are also known as reactive phosphates because they are the form of phosphates that react with the diagnostic chemicals used in laboratory tests checking for the presence of phosphates in a water sample.

- Polyphosphates (condensed phosphates). Polyphosphates are attached to salts and/or metals and are commonly used as food additives. Unstable in water, they eventually convert into orthophosphates.
• Bioavailable phosphorus. Numerous studies have shown that while the bioavailability (usability by plants and algae) of particulate phosphorus is only about 25%, that of dissolved phosphorus is almost 100%. Thus the Total BioAvailable Phosphorus (TBAP) in a water sample is all of its DRP plus just the BioAvailable component of its Particulate Phosphorus (BAPP): \[ \text{TBAP} = \text{DRP} + \text{BAPP}. \]

Phosphorus stratification. The buildup of phosphorus in the topmost few inches of soil. Phosphorus stratification has been one of the unintended consequences of the adoption of conservation tillage methods. Broadcasting of phosphate-enriched fertilizers atop residue-stabilized soil has led to the buildup of a phosphorus gradient within the uppermost layers of no-till treated fields. Resultant high concentrations of the nutrient in the top few centimeters of soil has been further strengthened by the breakdown of crop residues at the soil surface.

Phosphorus. A chemical element with the symbol, P, phosphorus is so chemically reactive that it is not found in a pure state under natural conditions. It is an essential component of cell membranes, nucleic acids, energy production, bone mineralization and many other biological processes. It is most commonly found as a member of a phosphate compound (PO$_4^{3-}$) or one of various derivatives of phosphates. Unlike other biologically important elements such as Carbon, Nitrogen and Sulfur, which are found in various forms in the atmosphere, earth and water, phosphorus has virtually no atmospheric component.

• Total Phosphorus (TP). Total phosphorus is a measure of all forms of phosphate-containing compounds—organic, inorganic, dissolved, particulate. Since the 1970’s, laboratories monitoring nutrients in streams, rivers and lakes throughout the nation have relied on TP as their primary tool for tracking changes in phosphorus within freshwater ecosystems.

• Soluble Reactive Phosphorus (SRP), Dissolved Reactive Phosphorus (DRP). These equivalent terms refer to orthophosphates that are dissolved in the water rather than attached to particles. EPA’s standard for dissolved (= soluble) phosphorus includes only those forms that can pass through a filter with 0.45 micron pores. For many purposes SRP is a superior tool for monitoring the environmental health of aquatic ecosystems since this is the form that is most readily bioavailable to plants and algae.

• Legacy phosphorus. The buildup of high concentrations of phosphorus-containing compounds after many years of broadcast fertilization and crop residue decomposition, especially in fields managed with conservation tillage.

Phytoplankton. Tiny to small members of the plankton community in a body of water with photosynthetic capability. Individual phytoplankton are commonly too small to be seen without the aid of a microscope. Worldwide, they include species from a wide array of taxonomic groups. In the Great Lakes region, they are predominantly members of the Cyanobacteria or green algae groups. They form the base of most food chains in large lakes.
Plankton. A diverse collection of aquatic organisms living in open water that are unable to swim against a current. Plankton are typically divided into two groups: phytoplankton and zooplankton.

Point sources of pollution. Pollutants entering a water body from a relatively confined region, such as the outflow pipe from a sewage treatment plant or an industry.

Reduced tillage. A cultivation method that leaves 15-30% crop residue on the soil.

Research I (R1) universities. The Carnegie Classification of Institutions of Higher Education is the standard framework for classifying American institutions of higher learning. R1 institutions are Doctorate-granting universities that are determined, by several factors, to have “very high research activity.” In additions to 2 other Research categories, the Carnegie Classification also includes 3 categories for Masters-granting institutions, 4 for Baccalaureate colleges, 9 for Associate colleges, 13 for Special Focus institutions and 1 category for Tribal colleges.

Severity Index (SI). A measure for rating an algal bloom season, where SI = predicted bloom intensity x predicted bloom extent (µg/L x km²) over the peak 30 days of a bloom.

Subsurface nutrient (or fertilizer) placement. A method of putting essential crop nutrients like nitrogen, phosphorus and potassium below the soil surface in the root zone available for plants to uptake. It is a BMP that protects surface water quality by dramatically decreasing nutrient runoff from a farmed field.

Soil and Water Assessment Tool (SWAT). USDA’s SWAT is a widely applied hydrological model used to quantify the impact of agricultural practices on the physical and chemical characteristics of rivers and streams in complex watersheds.

Soil Test Phosphorus (STP). An analysis of bioavailable phosphorus in the top 20 cm of soil obtained from various locations in a given field, typically by a Certified Crop Adviser, for the purpose of making a recommendation for the level and timing of applying phosphorus fertilizer to the field. Mehlich-3 and Bray Kurtz P1 (Bray P1) are the two most commonly used STP indices in the Great Lakes. The higher the STP value obtained for a given field, the greater the potential for DRP and PP runoff.

Soil and Water Assessment Tool (SWAT). A small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds. It is a public domain software-based model actively supported by the USDA ARS.

Thermocline. A thin layer in a deep, thermally-stratified lake separating the epilimnion above from the hypolimnion below. In the thermocline, temperature changes more rapidly with depth than it does in the layers above or below.

Tiling. A network of subsurface drainage conduits used to clear standing water from the clay-enriched to enable farming.
Time-weighted Mean Concentration (TWMC). A method of dealing with the fact that, since the Lab samples more frequently during high flow periods than in low, pollutant concentrations are generally higher during high flows. By weighting the concentration observed in a given sample by its “time-window” (the time between the last sample and the next one) and then averaging all such time-weighted concentrations for the month, this bias is eliminated. Compare Flow-weighted Mean Concentration (FWMC).

Total Kjeldahl nitrogen (TKN). A measure of the sum of nitrogen bound in organic substances, ammonia, and ammonium (NH₃/NH₄⁺). It does not include other forms of inorganic nitrogen such as nitrate and nitrite.

Total Maximum Daily Load (TMDL). A regulatory term in the Clean Water Act describing a plan for restoring an impaired waterway. A TMDL identifies the maximum amount of a given pollutant that the impacted body of water can receive while still meeting the assigned water quality standard for that pollutant in that body of water.

Tributary. A stream or river leading into another body of water. For example, the Maumee River is a major tributary of the Lake Erie’s Western Basin. Honey Creek is a tributary to the Sandusky River, which is a tributary to Lake Erie’s Central Basin.

Watershed, Drainage basin, Basin. Equivalent terms that refer to an area of land where precipitation collects and drains off into a common outlet. The size of a watershed varies with the size of the water body draining it. A creek has a small watershed, a river a larger one. The watershed of a river is comprised of all the watersheds of tributaries feeding into it.

Working Lands Buffer Program. An Ohio program that encourages producers in the Western Lake Erie Basin Watershed to establish year-round vegetative cover on eligible cropland. The program promotes the conversion, establishment and maintenance of forage/hay land on certain cropland acres. As the name implies “Working Lands Buffers” act as a buffer on cropland and provide another line of defense to filter surface water while allowing participants to harvest forage from established areas.

Zone of interaction or rhizospher. The top 4-5 cm of agricultural surface soil. It is the stratum where the soil and the roots of crop plants interact.

Zooplankton. A diverse group of organisms ranging in size from microscopic protozoans to readily visible arthropods like Daphnia. Although most have locomotory capabilities, they are small enough to drift with prevailing currents. Feeding on phytoplankton and/or each other, they are near the bottom of many aquatic animal food chains.
The 23 NCWQR HTLP riverine and creek sampling stations as of 2019