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Innovating for the Blue Economy:

Water Research at the URC

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I. Introduction and Summary of Findings

ABOUT THIS SERIES

This report is part of a series of studies that began in 2007 documenting the impact of the URC institutions (Michigan State University, University of Michigan, and Wayne State University) on specific sectors of the Michigan economy. Past reports have highlighted the life sciences industry, advanced manufacturing, alternative energy, and other sectors. See Appendix B, "Summary of Past URC Sector Reports."

This report highlights how URC universities are making a contribution to water-related research and innovation. The purposes of this report are:

- To define the scope and size of Michigan's water industry.
- To describe the areas of expertise that Michigan's URC universities have, and to quantify their contributions in advancing water-related research and innovation.

IMPORTANCE OF WATER TO MICHIGAN'S ECONOMY

Water is Michigan's most precious natural resource. The Great Lakes that surround the state hold 18% of the world's, and 90% of the nation's, surface freshwater.[1] The state also has more than 11,000 inland lakes and over 3,100 miles of coastline. [2] But this just scratches the surface of water's importance to the state:

- The Great Lakes are the most recognized aspect of the state's geography, making Michigan stand out on even completely unlabeled maps.
- Water defines the quality of life enjoyed by many Michigan residents, providing recreation opportunities, natural beauty, and a sense of place.
- Water affects public health in the state's communities, the ecosystems that support the state's quality of life, and support major sectors of the state's economy.

Water is also crucially important in the history—and future—of the state's economy. Michigan's entire economic history is bound to the Great Lakes:

- Manufacturing: the state's development path in becoming a world leader in manufacturing depended in part on the abundance of water and the access to customers and raw materials provided by Great Lakes shipping. For example, the development of Ford Motor Company's River Rouge Complex starting in 1917 depended on access the Rouge River, both for use of the water and transportation access.
- Agriculture and fisheries: the state's abundant fisheries and unique climates for agricultural products along the lakeshore have helped make agriculture one of the largest industries in the state.
- Tourism; the recreation opportunities and natural beauty provided by the Great Lakes and inland lakes support Michigan's tourism industry. One of the largest

1. National Oceanic and Atmospheric Administration, "About Our Great Lakes: Introduction," <http://www.glerl.noaa.gov/pr/ourlakes/intro.html>, accessed May 2014.
2. State of Michigan, "Michigan State Facts," <http://www.michigan.gov/mdot/0,4616,7-151-9622_11033_11151-67959--,00.html>, accessed May 2014.

industries in Michigan, tourism generated $17.7 billion of direct spending, $995 million in state taxes and 200,000 jobs in 2011.[3]

- Resource extraction: the navigable waters of the Great Lakes allowed Michigan's other natural resources such as minerals and timber to supply the region's economy—resources that made Michigan a fertile setting for the industrial development that has defined the last century.

Michigan's economic future is also deeply connected to meeting water-related challenges in the state, nationally, and globally using research and innovation.

Global Market for Water Technology and Innovation

There is a growing national and global market for water-related investment and innovation. For example:

- The demand for freshwater technology is estimated to be $400 billion per year globally, including $100 billion in the United States alone.[4]
- The U.S. EPA estimates that the nation's drinking water infrastructure systems will need more than $384 billion in investment by 2030.[5]
- Developing areas of the world are in urgent need of water-related infrastructure and sanitation projects. Independent estimates place global demand for such projects in the trillions of dollars over the next few decades.[6]
- Water for agriculture accounts for approximately 70% of global freshwater withdrawals, creating significant pressure on water resources as populations grow.[7]

Such water-related issues set the stage for companies and research universities in Michigan to contribute by providing water-related research and innovation and talented workers. Michigan's research universities have a depth and breadth

3. Dr. Sarah Nicholls, "Michigan Tourism Strategic Plan," Michigan State University, December 2012.
4. John Austin, Elaine Dezenski, and Britany Affolter-Caine, "The Vital Connection: Reclaiming Great Lakes Economic Leadership in the Bi-National US-Canadian Region" Brookings Institution Metropolitan Policy Program, 2008
5. "EPA Survey Shows $384 Billion Needed for Drinking Water Infrastructure by 2030," Environmental Protection Agency news release, June 4th, 2013.
6. The World Water Council estimates that 1.1 billion people lived without access to safe drinking water in 2002, and 2.6 billion lacked access to adequate sanitation.
Source: "Water Crisis: Towards a way to improve the situation." World Water Council, <http://www.worldwatercouncil.org/library/archives/water-crisis/>, accessed May 2014.
McKinsey & Company estimated in 2013 that the world could save more than $1 trillion per year by investing in high-productivity infrastructure projects, including the investment of around $10 trillion in water infrastructure projects. Source: "Infrastructure Productivity: How to Save $1 Trillion a Year," McKinsey & Company, January 2013.
7. "Facts and Figures," UNESCO, <http://www.unwater.org/water-cooperation-2013/water-cooperation/facts-and-figures/en/>, accessed May 2014.

of expertise that will help industries and governments address the challenges and opportunities presented by water-related issues.

Recognition of Water's Importance

Given the historic and current importance of water in Michigan, it is not surprising that the state's leaders are focusing on water as a strategic economic asset for the state going forward. These efforts include:

- Business leaders: Business Leaders for Michigan's "Michigan Turnaround Plan" has highlighted the Natural Resources Economy sector, including agriculture and tourism, as an economic asset to the state, and has stressed "the development of technologies that maximize the production of scarce resources in a sustainable way" as part of its strategy.[8] The Detroit Regional Chamber of Commerce joined with other Great Lakes region chambers (the Great Lakes Metro Chambers Coalition) to work together on a number of issues, including Great Lakes restoration. At the local government level, Macomb County's "Blue Economy Strategic Development Plan" released in 2012 and Oakland County's focus on water technologies are part of the overall effort to be competitive in emerging economic sectors.
- Multi-state and U.S.-Canada initiatives: the protection of the Great Lakes is the subject of extensive inter-state and international cooperation, including bodies such as the Great Lakes Commission of eight US states and two Canadian provinces; the International Joint Commission facilitating cooperation between the United States and Canada on protecting the trans-border environment, which includes the Great Lakes; the Council of Great Lakes Governors facilitating cooperation on environmentally responsible growth among US states and Canadian provinces bordering the Great Lakes; and agreements such as the Great Lakes Compact, a legal agreement signed by several US states governing how to manage the use of water in the Great Lakes Basin.
- State government initiatives: the Great Lakes are a center-piece to Michigan's "Pure Michigan" campaign. Michigan's state government coordinates policy "to protect, restore, and sustain" the lakes through the Office of the Great Lakes, which is part of the Department of Environmental Quality.[9]
- Think-tank research on the economic role of the Great Lakes: this includes work such as the Brookings Institution's Healthy Waters, Strong Economy report on the role the Great Lakes can play in transforming the region's economies.[10]

8. Business Leaders for Michigan, "Michigan Turnaround Plan", <http://www.businessleadersformichigan.com/storage/documents/michigan-turnaround-plan/Final%202014%20MTP.pdf>, accessed May 2014.
9. Statement on Office of the Great Lakes website. <https://www.michigan.gov/deq/0,4561,7-135-3306_29338---,00.html>, accessed April 25, 2014.
10. John C. Austin, "Great Lakes: Healthy Waters, Strong Economy," Brookings Institution, 2007, <www.brookings.edu/research/speeches/2007/09/05healthywaters-austin>.

OVERVIEW OF APPROACH

In defining the size and scope of Michigan's water industry, we identify the key sectors that directly implement water-related technology or are most vulnerable to water-related problems, including sectors such as water treatment, agriculture, manufacturing, and shipping. We have identified these water industry sectors by North American Industrial Classification System (NAICS) codes, and quantified the amount of Michigan employment in these sectors.

We highlight URC universities' contributions to research and innovation by identifying research projects on topics related to water quality and quantity, quantifying the amount of research awards over a five year period (from 2009-2013) on these topics, and describing several examples of cutting-edge research. We also identify degrees that URC graduates receive that allow them to contribute to water-related innovation in the private sector.

SUMMARY OF FINDINGS

1. URC universities advance water-related research and innovation on a vast array of topics.

URC universities have received more than $299 million in awards for research and outreach advancing water innovation from 2009 to 2013. This represents a significant research focus, as it is of similar size to the $303 million in awards for advanced automotive research at the URC from 2006-2011.[11]

The research activity spans dozens of departments and hundreds of individual principal investigators at the universities. The URC's particular areas of expertise include:

- Great Lakes restoration, including a wide variety of research on wetlands, fisheries, invasive species, and ecosystems.
- Water monitoring and filtering technologies, identifying and dealing with chemical and biological agents.
- Agriculture-related research, ranging from dealing with drought to minimizing and monitoring runoff from fields.
- Policy research to identify methods for dealing with water-related problems at the local, state, and national government level.
- Climate and weather research on topics affecting the quantity and quality of water present for agricultural, storm water, and other systems.

See "URC Contributions to Water Research and Innovation" on page 13.

11. "The URC's Contributions to Automotive Innovation," Anderson Economic Group, May 2012.

2. The URC universities produce thousands of graduates each year prepared to work in water-related industries and in water research fields.

In 2012 the URC universities awarded more than 3,400 degrees in more than two dozen fields that prepare graduates to analyze water-related issues. These include undergraduate and graduate degrees in fields ranging from Biology and Chemistry to Civil Engineering and Natural Resource Management. See "URC Programs and Initiatives Supporting Water Innovation" on page 23.

3. Michigan Ranks 4th in the nation in employment in industries closely related to water quality and quantity. With more than 718,000 workers, these sectors account for one in five Michigan jobs.

In this report we identify industry sectors that embody the opportunity to provide solutions to the global market for water-related products and services, and to advance research on topics that present vulnerabilities to major employers in the state. These sectors include:

- Core Water Products and Services industries provide products and services such as wastewater treatment, construction and repair of infrastructure, and scientific, engineering, and technical services.
- Water-Enabled Industries rely directly on the quality and quantity of available water, and include industries such as agriculture, fishing, manufacturing, and transportation.[12]
- Downstream Industries such as tourism are affected by water issues, but rely on water-related technologies in other industries. Downstream industries are not included in our quantitative analysis of water-related employment, but are also critical to the Michigan economy.

Michigan ranks 4th in the nation for employment in the Core Water and Water-Enabled sectors as a percentage of total employment. The state has employment of more than 718,000 workers in the Core Water Products and Services and Water-Enabled Industries sectors identified in this report, and is one of two states to rank in the top ten in percentage employed in both sectors. See "Defining Michigan's Water-Related Industries" on page 7.

12. See "Water-Enabled Industries" on page 9 for a more detailed description, including the illustrative example that commercial fishing is a "Water-Enabled Industry" but sportfishing operations are a "downstream" industry.

4. Water research and innovation represents an important strategic advantage for the State of Michigan, helping Michigan industries overcome challenges and seize opportunities in the global market for water technology.

The capacity for water-related research and innovation at Michigan's URC universities is a strategic asset for the state, for at least three reasons.

- Given Michigan's water resources and concentration of water-related industries (discussed in Finding 3 above), the state is among the best places to benefit from water-related research and innovation. Research on water-related issues gives entrepreneurs, existing companies, and early stage investors access to cutting edge research, thereby creating new markets and/or new companies.
- The global market for water-related expertise present opportunities for Michigan companies providing innovative water products and services (as discussed in "Importance of Water to Michigan's Economy" on page 1).
- The URC universities' expertise in key research areas, such as water monitoring and filtration and the relationship between water and agriculture (discussed in "The URC's Place in Water Research and Innovation" on page 25), will allow these universities to make a significant contribution to state, national, and global research efforts.

FORTHCOMING REPORTS ON THE BLUE ECONOMY

This report is the first in a collection of several works highlighting the value and importance of water to the economy of the state of Michigan. Other forthcoming reports include:

- The Michigan Water Strategy, as called for by Governor Rick Snyder in his special message on Energy and the Environment, will focus on the significant social, ecological, cultural and economic value of water to Michigan and highlight the central role and importance of water to the state and to the region.
- The Michigan Economic Center at Prima Civitas, in partnership with the Annis Water Resources Institute at Grand Valley State University is leading a "Growing Michigan's Blue Economy Initiative," designed to accelerate Michigan's activity in water placemaking, research and education, and new business development.

These efforts underline the importance of the Blue Economy to the future of Michigan.

ABOUT ANDERSON ECONOMIC GROUP

Anderson Economic Group is a research and consulting firm with expertise in public policy, economics, market research, and business valuation. AEG's Michigan clients include Automation Alley, Business Leaders for Michigan, the Small Business Association of Michigan, the National Federation of Independent Businesses, Oakland County, the City of Detroit, and numerous other private and public sector organizations. AEG has offices in East Lansing, Michigan and Chicago, Illinois. See "About the Author" on page C-1.

II. Defining Michigan's Water-Related Industries

In order to discuss the importance of water-related research and innovation to Michigan's economy, we must first define the industry. In this section we identify key portions of the state's economy that produce, implement, or are significantly affected by water-related research and innovation. We then quantify the employment in Michigan's water-related industries in 2012 and compare it to other states.

DEFINING INDUSTRY SECTORS DIRECTLY RELATED TO WATER

We used the North American Industry Classification System (NAICS), which is used by the Census Bureau to report industry data, to provide a repeatable basis for our industry definition that allows year-to-year and place-to-place comparisons within the United States.

Given the crucial role that water has played in the state, and the continued importance as an asset of the state, it is tempting to include a majority of the state's economy. Since this report is focused on the URC universities' contribution to the state's water industry, we have a somewhat narrower focus. We were guided by the following question:

> *What industries most directly benefit from advancements in water-related research and innovation affecting water quality and quantity?*

We have identified two sectors of the economy that fit:

1. **Core Water Products and Services (CWPS).** These industries contain companies that are water technology producers and service providers. This sector will include producers of water processing technology such as filters, water treatment facilities, and service-providing companies that assess and find solutions to problems related to water quality and quantity.
2. **Water-Enabled Industries (WEI).** This will include the many parts of the economy that do not directly produce or implement advanced water technology solutions, but are nevertheless affected by changes in both the quality and quantity of available water, and to regulations governing the quality of water runoff or effluent.

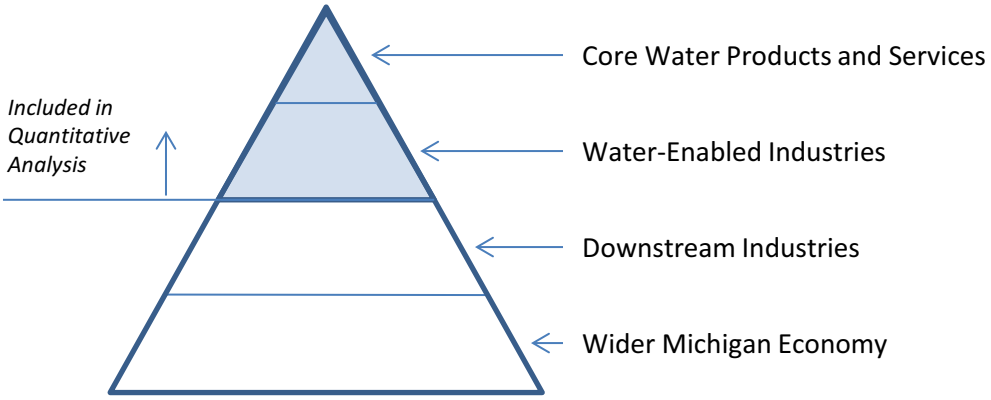
There are, of course, many other parts of the state's economy that depend crucially on water to operate, but are "downstream" of the businesses that directly use and apply water-related technologies. For example, many businesses and much investment in property in the state is related to tourism and recreation such as fishing and boating. These activities can be directly affected by water-related issues and research such as cleaning effluent from industry and municipal water treatment facilities, and aquatic invasive species affecting transportation, industrial water intakes, property values, and sport fishing opportunities. These "downstream industries" are both economically important and water-

related, but are not included in our quantitative analysis of employment in water-related industries because they are less likely to *directly implement* the advances in water-related research and technology discussed in this report.

The wider-economy of the state is connected to each of these sectors, as businesses in CWPS, WEI, and downstream industries purchases goods and services.

These sectors of the state economy can be thought of as layers of a pyramid of water-related industries in the state:

FIGURE 1. Economic Sectors Related to Water



CORE WATER PRODUCTS AND SERVICES

The Core Water Products and Services (CWPS) industry includes six industry sectors that develop, sell, or implement technology related to water quality and quantity. These sectors include businesses that will be called upon to help address challenges in water quality and quantity that affect quality of life, health, and the operation of businesses in the wider economy.

Among the CWPS sub-sectors are:

- 1 Manufacturing sub-sector that includes production of water filtration media.
- 2 Service sub-sectors focused on waste treatment and remediation services.
- 4 Service sub-sectors providing scientific, engineering, and technical services.

See Table A-1 on page A-5 for a complete list of the sub-sectors included in the CWPS sector.

WATER-ENABLED INDUSTRIES

Water-Enabled Industries (WEI) use water as a key input to their operations, or they have significant water discharge that must be processed properly, or both. Such industries are the most susceptible to changes in water quality in the environment, changes in the availability of water suitable for use, and changes in regulations affecting water discharges. As a result, they are the most likely to pose the questions that URC researchers seek to answer, and would be the most direct beneficiaries from breakthroughs. One example that illustrates the distinction: both commercial fishing and sportfishing tour operations might be thought of as "downstream" industries because they rely on other industries to play their part in maintaining clean water and healthy water ecosystems. However, commercial fishing is also directly regulated as part of broader ecosystem preservation and water quality efforts because its businesses operate on a larger scale and have can directly impact the sustainability of Great Lakes fisheries. Therefore, commercial fishing is included in the WEI sector, while sportfishing is not.

The WEI sector includes a more expansive portion of the economy, including 62 industry sub-sectors. Among the sub-sectors in the WEI sector are:

- 15 Agriculture, fishing, forestry, and other related sub-sectors.
- 4 Mining and other extractive sub-sectors.
- 56 Manufacturing-related sub-sectors, including the advanced manufacturing that is a core element of the auto industry.
- 2 Transportation-related sub-sectors, including Great Lakes shipping.

See Table A-1 on page A-5 for a complete list of the sub-sectors included in the WEI sector.

EMPLOYMENT IN MICHIGAN'S WATER INDUSTRIES

Michigan's water industry employment was more than 718,000 in 2012, including over 138,000 in Core Water Products and Services, and more than 581,000 in Water-Enabled Industries, as shown in Table 1 below and in Table A-2 in Appendix A.

TABLE 1. Total Water Industry Employment in Michigan and the U.S., 2012

	Michigan	U.S. Total
Core Water Products and Services	138,026	3,948,804
Water-Enabled Industries	581,028	13,942,918
Total Water Industry	718,704	17,851,911
As % of Total Employment	21.3%	16.1%
Reference: Total Employment	*3,373,672*	*110,645,869*

Source: U.S. Bureau of Labor Statistics, U.S. Agriculture
Analysis: Anderson Economic Group

The state's water industry sectors make up a larger proportion of Michigan's employment than for the nation as a whole. In fact, Michigan is 4th among U.S. states in its prevalence of CWPS and WEI employment and has water-related employment intensity almost 30% above the national average of 16.1%, as shown in Table 3.

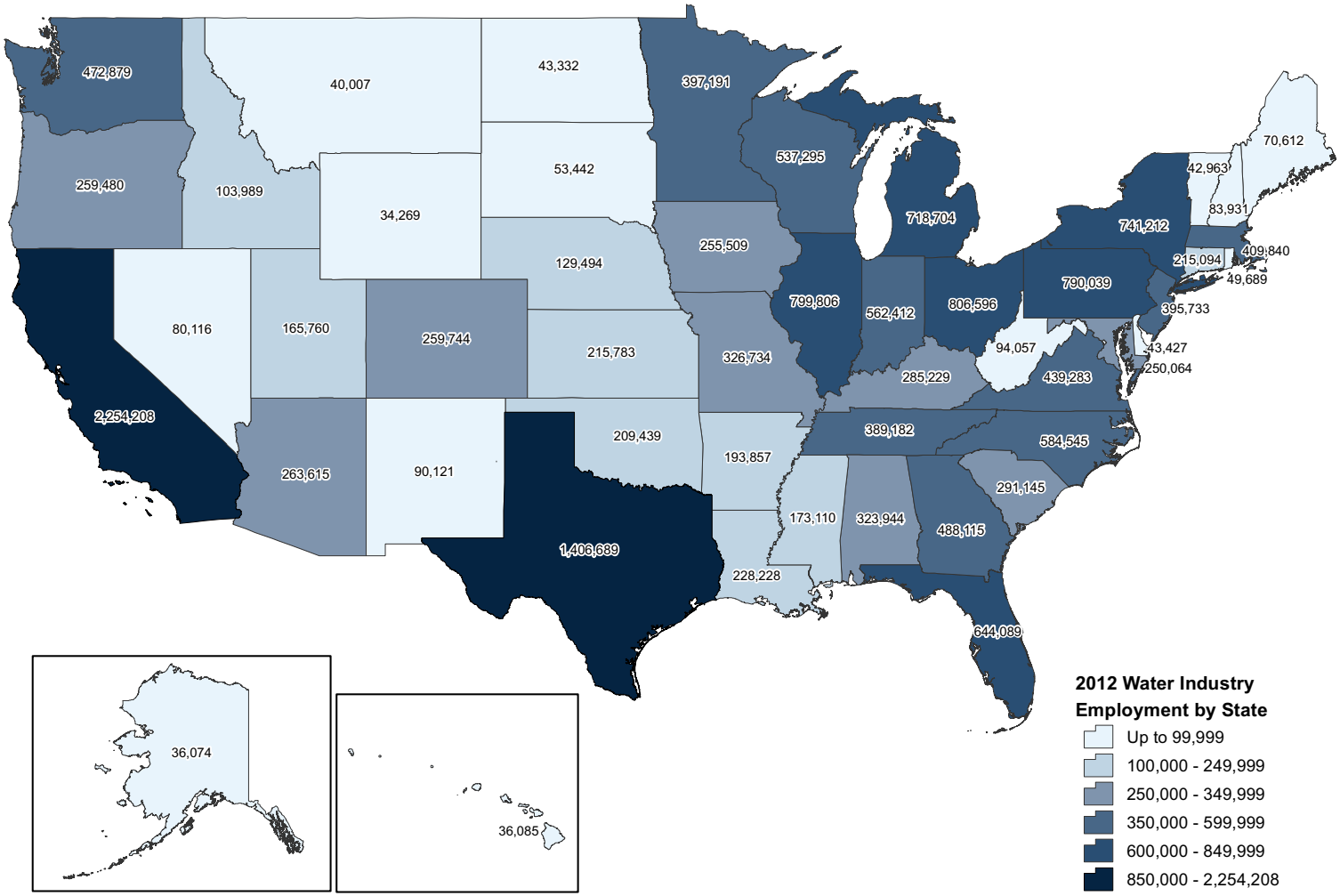
TABLE 2. Top 10 States in Water Industry Employment Intensity, 2012

		% of Total Employment			State Rank (% of Total Employment)		
State	**Total Water Related Employment**	**Core Water Products and Services**	**Water-Enabled Industries**	**Total Water Related**	**Core Water Products and Services**	**Water-Enabled Industries**	**Total Water Related**
Indiana	562,412	2.1%	21.2%	23.3%	46	1	1
Wisconsin	537,295	2.1%	21.1%	23.2%	45	2	2
Alabama	323,944	3.4%	18.7%	22.1%	17	4	3
Michigan	**718,704**	**4.1%**	**17.2%**	**21.3%**	**10**	**8**	**4**
Idaho	103,989	4.2%	16.4%	20.6%	9	10	5
Iowa	255,509	1.6%	19.0%	20.6%	50	3	6
Arkansas	193,857	1.9%	18.7%	20.5%	47	6	7
Mississippi	173,110	1.7%	18.7%	20.4%	48	5	8
Kansas	215,783	3.1%	17.0%	20.1%	24	9	9
Washington	472,879	3.9%	15.9%	19.9%	12	14	10
United States	*17,851,918*	*3.6%*	*12.6%*	*16.1%*			

Source: U.S. Bureau of Labor Statistics, U.S. Agriculture
Analysis: Anderson Economic Group

The industry reaches throughout the nation, as shown in Map 1, "Water Industry Employment in US States, 2012," on page 11. While total employment is highest in high-population states (such as Texas and California), there is a concentration in Great Lakes states, with more than 3.8 million total workers in water-related industries in Michigan, Wisconsin, Minnesota, Illinois, Indiana, and Ohio. As with the Michigan-based employment in these sectors, these jobs are closely connected to challenges in the availability and management of high quality water, and to opportunities in offering solutions to these challenges.

Map 1. Water Industry Employment in US States, 2012



Source: U.S. Bureau of Labor 2012 Quarterly Census of Employment and Wages (QCEW); 2011 QCEW; 2011 Census Bureau County Business Patterns (2011); U.S. Census of Agriculture (2007). Analysis: Anderson Economic Group, LLC.

DOWNSTREAM INDUSTRIES AND THE BROADER MICHIGAN ECONOMY

Downstream industries are often directly affected by issues of water quality and quantity, and are economically important to the state. They are, nevertheless, not included in our quantitative analysis of employment in water-related industries because they are less likely to *directly implement* the advances in water-related research and technology discussed in this report.

Examples of such important industries include major contributors to the state's economy, including:

- Tourism; one of the largest industries in Michigan, generating $17.7 billion of direct spending, $995 million in state taxes and 200,000 jobs in 2011.[13]
- Fisheries; the Great Lakes fishery is valued at $7 billion annually, and provides 75,000 direct jobs. Approximately 5 million people fish it annually.[14]
- Sport fishing; sport fishery contributes $4 billion to the national economy.[15]

In addition to the "downstream" industries affected by water quality and quantity, water underpins quality of life in the state more broadly. Water quality affects both the health and the recreation opportunities for Michigan residents. These factors, in turn, are part of a broader set of factors that each resident and potential resident consider when evaluating where they would like to live, work, play, and visit.

13. Dr. Sarah Nicholls, "Michigan Tourism Strategic Plan," Michigan State University, December 2012.
14. Great Lakes Fishery Commission, "Budget Summary, Fiscal Year 2012," February 2011.
15. National Oceanic and Atmospheric Administration, "About Our Great Lakes: Economy," <http://www.glerl.noaa.gov/pr/ourlakes/economy.html>, accessed May 2014.

III. URC Contributions to Water Research and Innovation

The URC universities contribute to innovation in water-related industries through their extensive research and development and outreach activities by researchers, and by educating workers that advance innovation in the private sector. This section describes the scope and size of the water-related research activity at the URC universities, describes several examples of such research, and identifies the programs, degrees, and centers at the schools that educate potential private sector water innovators.

SCOPE AND SCALE OF URC'S WATER-RELATED RESEARCH AND OUTREACH

URC universities produce research on a very wide variety of water-related topics. We examined data from the universities on research projects awarded funds from governments, private companies, foundations, and other sources, that were active in the years 2009 to 2013. We identified more than 2,100 awards for research, education, and outreach activities.[16] The funds awarded for these projects totaled more than $299 million, representing 2.6% of total URC university research awards, which totaled $11.4 billion over the period. This represents a significant research focus, as it is of similar size to the $303 million in awards for advanced automotive research at the URC from 2006-2011.[17]

The breadth of topics undertaken by URC researchers is remarkable, as shown in Figure 2 on page 14. The URC's particular areas of expertise (based on number of projects and funding levels) include many areas of importance at the regional and global levels. These include:

- Great lakes restoration, including a wide variety of research on wetlands, fisheries, invasive species, and ecosystems.
- Water monitoring and filtering technologies, identifying and dealing with chemical and biological agents.
- Agriculture-related research, ranging from dealing with drought to minimizing and monitoring runoff from fields.
- Policy research to identify methods for dealing with water-related problems at the local, state, and national government level.
- Climate and weather research on topics affecting the quantity of water present for agricultural, storm water, and other systems.

Awards for research and outreach span across the universities and include many departments, ranging from Natural Resources and Environment, to Chemistry, to Agricultural Extension offices, to Biology. In total, 341 different researchers were principal investigators on water-related projects at URC universities.

16. Education and outreach includes, for example, consulting for a State of Michigan Department, educating the public, and engaging students and scholars in science related to the Great Lakes.

17. "The URC's Contributions to Automotive Innovation," Anderson Economic Group, 2012.

FIGURE 2. Water Research at Michigan's Research Universities

Nearly **$300 million** in research & outreach, including:

1. Non-Point Source Pollution
2. Drought-Resistant Plants
3. Water Policy Research & Planning
4. Waterborne Illness & Disease
5. Sustainable Land & Water Management
6. Point Source Pollution
7. Wastewater & Sewer Infrastructure & Treatment
8. Sustainable Water Use by Industry
9. Climate Modeling
10. Aquatic Invasive Species
11. Great Lakes Restoration & Protection
12. Sustainable Water Use by Agriculture
13. Beach Quality
14. Storm Water Management
15. Drinking Water Safety
16. Groundwater Monitoring
17. Great Lakes Water Transportation

Illustration by Lambert, Edwards & Associates for University Research Corridor

HIGHLIGHTS OF SPECIFIC RESEARCH INITIATIVES AND CENTERS

Each of the URC universities contributes water-related research and innovation on multiple scales, including specific projects by individual researchers, participation in larger initiatives across the state and region, and the establishment of specialized research teams and centers that can apply multidisciplinary expertise to water-related questions. The examples in this section show how the capacity for water-related research is being applied at URC universities.

Leading in Water Safety Research and Service

Dr. Joan Rose, Co-Director for both Center for Advancing Microbial Risk Assessment (CAMRA) and its Center for Water Sciences (CWS), is developing new genetic analytics to study waterborne health threats. Dr. Rose is an international authority on water microbiology, water quality and public health.

Water quality studies today tend to focus on the indicators of pathogens, but Dr. Rose's work targets actual threat agents such as viruses, mapping water quality and health risks in Michigan, the Great Lakes and throughout the world.

Dr. Rose is a pioneer in the emerging science of viral metagenomics—sequencing virus DNA in water sources, discharges and shipping ballast using next-generation high-throughput technology. Such technology promises to significantly improve methods to protect water and food supplies, and Dr. Rose is applying the technology to assess the safety of fresh produce.

Her global activity includes investigation of waterborne disease outbreaks and the study of water supplies, treatment, and reclamation. Her applied research interests include study of microbial pathogens in recreational waters and climatic factors impacting water quality.

University Collaboration on Michigan Sea Grant

Surrounded by four of the five Great Lakes, Michigan is at the epicenter of the impact of responsible water management and ecosystem stewardship. Leading the initiative to protect the state's and region's greatest natural asset is Michigan Sea Grant, part of the National Sea Grant College Program and a cooperative program of the University of Michigan and Michigan State University.

Michigan Sea Grant is charged with identifying environmental challenges, developing solutions, and supporting research to protect and restore the bodies of water so critical to the health and culture of its residents and economic vitality of its industries.

Current research projects include expansion of aquaculture into a sustainable seafood industry (MSU), spawning habitat construction in the St. Clair and Detroit rivers (U-M), and assessment of lingering impacts of copper mining in the Torch Lake area of the Keweenaw Peninsula (Michigan Tech). Most recently, Wayne State University researchers won a Sea Grant award to support

study of stable open channel design and another to study the muck ecosystem in Saginaw Bay.

Following an integrated assessment approach, research teams create tools and build partnerships that help citizens better address challenging coastal issues - such as fish contaminants, stormwater runoff, or wind energy conflicts. Sea Grant specialists apply research to real-life issues through their work with natural resource managers, industries and stakeholder groups to promote science-based decision-making.

As part of the University of Michigan's School of Natural Resources and Environment and Michigan State University's Extension Greening Institute, both institutions provide matching funds to support research, education, and outreach programs, as well as issue grants. Michigan Sea Grant has supported at least 150 peer-reviewed publications (1990-2008), awarded 41 fellowships for graduate students since 1982, and funded $34 million in research since 1969.

Today researchers across the URC have secured funding to support their water research from Michigan Sea Grant, as have their colleagues at other universities in the state leading water research efforts, including Grand Valley State University's Annis Water Resources Institute, and Michigan Technological University's Center for Water and Society and Great Lakes Research Center. Of the 33 grants made by Michigan Sea Grant, two-thirds were in applied research.

Understanding Chemical Movement and Processes in the Oceans

Dr. Mark Baskaran, Ph.D., Professor of Geology in the College of Liberal Arts and Sciences at Wayne State University, is following the pathways and cycling of two trace elements in the Pacific Ocean from Peru to Tahiti. His research is working to advance understanding of the movement of chemical compounds through the world's oceans.

His research examines levels of polonium (Po) and lead (Pb) isotopes in water samples from Peru to Tahiti, investigating how much carbon is exported from the upper 100 meters of ocean water to deeper waters, and how hydrothermal waters released from the bottom of the ocean affect the removal of polonium and lead. While some of the key trace elements and isotopes (TEIs) sampled have been induced by humans, others are the result of radioactive decay of naturally occurring uranium.

Dr. Baskaran's work is part of the National Science Foundation's GEOTRACES project. GEOTRACES brings together scientists from 30 countries to study how environmental changes - especially those resulting from increased industrial and commercial activity in the last 200 years - have affected distribution of key TEIs and chemical processes taking place in the ocean.

Based on his previous research with polonium and lead isotopes, Dr. Baskaran believes samples from the selected area will prove useful in tracking these changes. His team's data will be added to that of researchers studying other TEIs to provide the best possible assessment of what has occurred and when, especially within the past century.

Building Capacity for Interdisciplinary Water-Related Research

The University of Michigan Water Center, part of the Graham Sustainability Institute, is a multidisciplinary research group that sits across multiple schools at the university and works with researchers from universities across the Great Lakes region.

Focused on “translational knowledge”, research applied to real-world problems, the center has two main goals. First, with funds from a grant by the Erb Family Foundation, the Center awards grants to researchers working on Great Lakes restoration issues with practitioners such as state government resource managers. Second, the Center is focused on building and maintaining capacity for solving problems using researchers from multiple schools, departments, and disciplines. This includes working with the Graham Sustainability Institute's Integrated Assessment Center to address complex issues such as Great Lakes water levels, and using research grants to seed cross disciplinary efforts to build research programs, fostering ongoing collaboration.

To support Great Lakes restoration and protection efforts, the U-M Water Center awarded eight research grants, totaling nearly $2.9 million, to multidisciplinary teams led by researchers at universities in Michigan, Indiana, Wisconsin, Minnesota and New York. The projects support efforts to restore native fish migrations across the Great Lakes Basin, improve lake water quality, map Great Lakes environmental stressors, and strategies for restoring aquatic ecosystems including wetlands and river watersheds. One of the eight projects funded is focused on guiding ecological restoration of Saginaw Bay: “Saginaw Bay optimization tool: linking management actions to multiple ecological benefits via integrated modeling”. David Karpovich of Saginaw Valley State University is the principal investigator of the project aimed at reducing nutrient runoff from agricultural land into Michigan's Saginaw Bay, including efforts to encourage voluntary implementation of best management practices by farmers. This Water Center-funded study will include a retrospective assessment of GLRI and MAEAP projects within the Kawkawlin and Pigeon/Pinnebog river sub-watersheds, as well as development of priorities to guide future conservation efforts

Monitoring Environments and Improving Farm Efficiency from the Sky and Under Water

Dr. Bruno Basso, Associate Professor of Geological Sciences at Michigan State University, is pursuing improved agricultural efficiency through a combination of computer simulation and new remote sensing technology. Utilizing technol-

ogy including aerial drones, Dr. Basso's team models crop growth to precisely apply water and fertilizer depending on current conditions. This system can also identify strategies for adapting to long-term drought and extreme weather anticipated to result from climate change.

Threats to bodies of water such as algae blooms, which rob the ecosystem of oxygen, often aren't apparent until the damage is done. Dr. Xiaobo Tan, Associate Professor of Electrical and Computer Engineering at Michigan State University, is developing fish-like robots that will provide more frequent and thorough monitoring of water sources. Initially building perch-sized underwater robots carrying water quality sensors and transmitting gear, he is now building larger craft, employing buoyancy "gliding" technology together with fin locomotion to enable the autonomous craft to operate for longer periods, over greater distances.

Research on Ballast Water Treatment and Verification

The increasing number if aquatic invasive species in the Great Lakes poses a major a threat to the health and vitality of the lakes themselves and industries relying on them. Invasive species damage the food chain, beaches and infrastructure, costing industries, businesses and citizens in the Great Lakes region millions of dollars each year. Most of these invasive species arrived in the ballast water tanks of ships originating travel from the Atlantic Ocean.

These ships carry millions of gallons of water from coastal port areas in their ballast tanks to maintain stability in transit. At each port of call, the ballast water is discharged, along with the live organisms that were transported. New regulations will soon require ships to treat ballast water outside of the Great Lakes to eliminate all live organisms before the ballast water is discharged.

Current monitoring and treatment methods take days to administer and are difficult to enforce in the time-sensitive transportation industry. Dr. Jeffrey Ram, Ph.D., Professor of Physiology in the School of Medicine at Wayne State University, is leading a multidisciplinary team developing an automated, shipboard, rapid-testing system that will be able to report "in real time" the presence of live organisms in ballast water, after it has been treated.

To create this new system, the researchers are adapting chemistry used to detect live salt water organisms in fresh water samples, applying automation technology. Dr. Amar Basu, Ph.D., Assistant Professor of Electrical and Computer Engineering in the College of Engineering at Wayne State University, is collaborating with Dr. Ram on the project. WSU has a provisional patent for the automation technology based on a vital staining process in which a colorless chemical interacts with enzymes, producing bright fluorescence in live organisms. This new technology provides results in minutes, leading to a paradigm shift in the area of ballast water management.

Research on Quantifying the Water-Related Financial Risk in Stock Ownership

Dr. Peter Adriaens, Professor of Civil and Environmental Engineering and Professor of Entrepreneurship and Strategy at the University of Michigan, is working on water risk analysis techniques at the university and in the private sector. He is pursuing research identifying the specific water-related risk associated with owning the stock of publicly-traded companies in water-sensitive sectors, including utilities, mining, and steel production.

Identifying financial risk associated with ownership of specific companies based on their public disclosures of water management policies and financial data could influence both public and private efforts to manage water risks globally. In particular, having more public information on water-related risks to global firms' financial health could lead fund managers and other investors to influence companies and governments in key areas to provide better data, better policy, and better practices on issues related to water quality and quantity.

Exploring Coupled Human and Natural Systems Globally

Dr. Jianguo "Jack" Liu, Director of the Center for Systems Integration and Sustainability at Michigan State University, and doctoral student Wu Yang examined at China's water supply and quality problems, lessons learned from these problems and management strategies that hold solutions for China and the rest of the world.

China's crisis is daunting, though not unique. Two-thirds of China's cities have water shortages, more than 40 percent of its rivers are severely polluted, 80 percent of its lakes suffer from eutrophication (an overabundance of nutrients) and about 300 million rural residents lack access to safe drinking water. Recent floods in Beijing overwhelmed drainage systems, resulting in scores of deaths.

China has dedicated enormous resources, nearly $635 billion, which represents a quadrupling of investment in the next decade, mainly for engineering measures. In a recent journal article, the Dr. Liu outlined China's water crisis and recent leapfrog investment in water conservancy, suggesting to address complex human-nature interactions for long-term water supply and quality solutions.

Advancing Ecological Restoration of the Great Lakes

The invasion of zebra mussels and quagga mussels have caused dramatic ecological effects on the Great Lakes ecosystems, including changes in fish abundance, local extinction of native mussels, and profound changes in benthic invertebrates (important for decomposition of organic matter) and more.

With the help of a two-year, $250,000 grant from the United States Geological Survey (USGS), scientists led by Donna Kashian, Ph.D., Assistant Professor of Biological Sciences at Wayne State University, are heading up research identifying a chemical found in algae that may inhibit spawning in the invasive zebra and quagga mussels. The research aims to identify chemical cues released by algae, and determine ways to develop an ecological-scale control strategy to disrupt reproduction.

Their preliminary research has demonstrated that algae produce chemicals that stimulate or inhibit zebra and quagga mussels spawning. Rather than focusing on toxic, non-specific chemicals used in water treatment facilities and power stations to kill mussels, Dr. Kashian's team hopes to regulate mussel reproduction and reduce their populations at ecosystem scales through natural, potential species specific chemical cues released by algae.

Dow Sustainability Fellows Program - Preparing Future Sustainability Leaders

Made possible by the Dow Chemical Company, the Dow Sustainability Fellows Program at the University of Michigan supports full-time graduate students and postdoctoral scholars at the university committed to finding interdisciplinary, actionable, and meaningful sustainability solutions on local-to-global scales. The program aspires to prepare future sustainability leaders to make a positive difference in organizations worldwide.

The diverse array of fellows brings together many interests related to water, energy, health, consumption, green chemistry, transportation, built environment, climate change, biodiversity, human behavior, environmental law, and public policy, among others. The program comprises masters/professional degree, doctoral, and postdoctoral fellows, who engage with one another within and across cohorts, thrive on collaboration, learn to employ interdisciplinary thinking, experience diverse stakeholder perspectives, and implement projects with significant potential for impact on local-to-global scales.

To foster high-impact sustainability collaborations across the University of Michigan, the Dow Sustainability Fellows program includes a competition for applied sustainability projects that cut across disciplines and academic levels, and involve U-M students at all academic levels. This is the Distinguished Awards for Interdisciplinary Sustainability.

Turning Environmental Liabilities into Assets

Dr. Steve Safferman, Associate Professor of Biosystems and Agricultural Engineering at Michigan State University, focuses his research on effectively recycling wastewater and farm waste in an effort to protect the environment.

A leader in the study of anaerobic digestion of manure and other waste to generate energy, Dr. Safferman and his team are also researching methods to remove phosphorous from wastewater. Often found in wastewater, agricultural and residential runoff, phosphorus finds its way into lakes and streams, promoting growth of oxygen-depleting algae and plant life, choking other life forms. Certain forms of phosphorus can also be toxic.

Dr. Safferman has partnered with a private sector company, testing a new filter to reclaim phosphorus which can be reused as fertilizer. Another byproduct of phosphorus removal, clean water, also becomes an asset as opposed to an environmental liability.

The Huron to Erie Alliance for Research and Training (HEART) Freshwater Center

The HEART Freshwater Center is a collaborative effort between Wayne State University, Macomb Community College, Huron-Clinton Metropark Authority and Macomb County focused on developing field facilities at Lake St. Clair Metropark and Belle Isle along the Huron-to-Erie corridor, a body of water shared by the United States and Canada connecting the upper and lower Great Lakes.

The Wayne State University engagement includes an interdisciplinary team of researchers led by Dr. Carol Miller, Professor of Civil and Environmental Engineering in the College of Engineering. For Dr. Miller, the opportunity to conduct research at a freshwater center shared by key regional partners provides an advantage in maximizing shared resources and expertise in a real-world urban laboratory, unique in its geography at a critical intersection for Great Lakes water.

The goal of HEART is to design activities and facilities to attract scientists, educators and students from national and international institutions to conduct innovative research focusing on urban systems and the environment. Particular areas of interest include storm water runoff (green infrastructure), beach health, wetland ecology and marsh restoration, invasive species, algae and nuisance vegetation, fisheries-related research, and emerging contaminants in urban waterways. HEART's training and research activities will impact more than 4 million people along the waterway, who will receive recreational, economical and ecological benefits from the project. In addition, HEART will inform watershed managers and policy makers from a variety of urban freshwater environments.

Interdisciplinary Research on Algae Blooms in Lake Erie

The 2011 Lake Erie algae bloom, composed almost entirely of toxic blue-green Microcystis algae, was the largest in the lake's recorded history. Concentrations of mycrocystin, a liver toxin produced by the algae, peaked at about 224 times

World Health Organization guidelines. An algae bloom is a rapid buildup of algae in a body of water, and harmful blooms are those that damage other organisms, including humans, through the production of toxins or by other means. Algae blooms can foul harbors, clog boat motors, reduce fish populations and sometimes lead to the formation of low-oxygen "dead zones" where most aquatic organisms cannot survive.

To analyze the likelihood of future massive blooms in Lake Erie, an interdisciplinary team of 18 researchers from the University of Michigan and 11 researchers from eight other universities explored factors that may have contributed to the event, such as land use, agricultural practices, precipitation, temperature, wind, lake circulation and surface runoff. The researchers found that a series of intense spring rainstorms and runoff events resulted in record-breaking levels of phosphorus, a nutrient in crop fertilizers that also fuels rampant algae growth, washing into western Lake Erie. This set the stage for an algae bloom more than three times larger than any previously observed Lake Erie algae bloom, including blooms occurring in the 1960s and 1970s, when the lake was famously declared dead.

Other contributing factors include the recent widespread adoption of no-till farming and other agricultural practices that have increased the availability of a type of phosphorus that promotes algae growth. These agricultural practices, coupled with intense spring rainstorms that are expected to be more common with climate change, led the research team to conclude that Lake Erie's monumental 2011 algae bloom is more likely to occur again in the future.

Measuring Metals in Stormwater Runoff and Wetlands

High concentrations of toxic metals in aquatic systems are a known threat to the environment, especially in urban areas where rainwater runoff carries large amounts of pollutants. Wayne State University researchers are working to better measure these pollutants as a step toward designing efficient "green" systems for removing heavy metals like copper, cadmium and lead from stormwater.

Although urban areas comprise just 3 percent of the United States' land mass, stormwater from those areas is the main source of pollutants in 13 percent of all rivers, 18 percent of all lakes and 32 percent of all estuaries. Passive treatments to mitigate that impact include rain gardens and bioswales. Such treatments conserve energy, resources and finances, but researchers say their ability to retain heavy metals is critically undefined.

Shawn McElmurry, Ph.D., Assistant Professor of Civil and Environmental Engineering at Wayne State University, and Parastoo Hashemi, Ph.D., Assistant Professor of Chemistry at Wayne State University, are developing a technology that can rapidly quantify concentrations of heavy metal in environmental systems. Their electrochemical technique utilizes a small carbon fiber a few

micrometers in diameter to detect metals quickly, with approximately 100 measurements a second.

Known as fast-scan cyclic voltammetry, it uses an electrical current to attract metals to the fiber surface. When metals touch the electrode, they alter the current in unique ways, making it possible to identify different types of metals. While traditional voltammetry is much slower, taking up to five minutes, and is more prone to fouling, this new technique is faster and more versatile, allowing for quantification of metals within milliseconds in environmental systems. Ultimately McElmurry and Hashemi's instrument will be used to measure metals in stormwater runoff and wetlands to help reduce the amount of pollution entering the Great Lakes.

URC PROGRAMS AND INITIATIVES SUPPORTING WATER INNOVATION

Each of the URC universities supports research and innovation in water technology with several programs, centers, and degree programs. These activities support innovation at the universities, in government, and in private companies.

Table 3 below lists 30 departments, centers, programs, and initiatives at URC universities that support water research and innovation. These include individual departments, interdisciplinary efforts, and multi-institutional initiatives fostering collaboration among universities.

TABLE 3. Current Water-Centered Departments, Centers, Programs, and Initiatives at URC Universities

University	Department, Center, Program, or Initiative	School or College
MSU	Global Water Initiative	Institutional
MSU	Center for Water Sciences	Institutional
MSU	Department of Civil and Environmental Engineering	College of Engineering
MSU	Hydrology & Water Resources	College of Engineering
MSU	Department of Geological Sciences – Environment	College of Natural Science
MSU	Environmental and Science Program	Institutional, Graduate Education
MSU	Department of Fisheries & Wildlife – Landscape Limnology	College of Agriculture and Natural Resources
MSU	Institute of Water Research	Institutional, MSU Extension
MSU	Center for Systems Integration and Sustainability	Institutional
MSU/U-M	Coast Watch Sea Grant (NOAA & UM)	Multi-Institutional (U-M) - College of Agriculture and Natural Resources, MSU Extension
MSU	Land Policy Institute	Institutional, School of Planning, Design and Construction
MSU	Kellogg Biological Station: Long Term Ecological Station	Institutional
MSU	Center for Advancing Microbial Risk Assessment	Multi-Institutional (Drexel)
MSU	Aqua Clara Collaboration	Bioeconomy Institute
U-M	Water Center	Institutional, Graham Sustainability Institute
U-M	Frederick A. & Barbara M. Erb Institute	Ross School of Business, School of Natural Resources and Environment
U-M/MSU	Michigan Sea Grant	Multi-Institutional (MSU), School of Natural Resources and Environment
U-M	UM Biological Station – Pellston	School of Literature, Sciences, and the Arts
U-M	Cooperative Institute for Limnology & Ecosystems Research	School of Natural Resources and Environment
U-M	Institute for Fisheries Research	School of Natural Resources and Environment
U-M	Civil and Environmental Engineering	College of Engineering
U-M	Environmental Health Sciences	School of Public Health
WSU	Institute of Environmental Health Sciences	Institutional
WSU	Urban Watershed Environmental Research Group	Institutional, College of Engineering
WSU	College of Engineering Civil and Environmental Engineering	College of Engineering
WSU	RISEUP: Research Internships for a Sustainable Environment with Undergraduate Participation	School of Medicine
WSU	Huron to Erie Alliance for Research & Training	College of Engineering
WSU	Sustainable Water Delivery	College of Engineering
WSU	Lumigen Instrumentation Center	College of Engineering - Chemistry

Source: University Research Corridor

We have also identified 26 Bachelor's, 28 Master's, and 14 Doctoral programs that equips graduates interested in the area to work on water-related issues. These degrees include biological and physical sciences, as well as degrees focused on agriculture and geology. See Appendix A for a list of the degrees included.

TABLE 4. Degrees Awarded in Water-Related Fields, 2012

	Michigan State University	University of Michigan	Wayne State University	Total
Bachelor's	1,121	754	273	2,148
Master's	164	563	171	898
Doctorate	102	217	46	365
Total	1,387	1,534	490	3,411

Source: IPEDS
Analysis: Anderson Economic Group, LLC

INNOVATION AND TECHNOLOGY TRANSFER

Universities play a direct role in using research to drive innovation at the earlier stages, when basic and applied research are needed. Each URC university's technology transfer and commercialization office help this research make an impact in the private sector by shepherding new technologies through the commercialization process, including the patent, licensing, and start-up processes. Since 2002, the URC universities have assisted with the start-up of 163 companies. A number of these start-ups fit within the Core Water Products and Services and Water-Enabled Industries defined in this report. Currently there are dozens of water-related technologies available for licensure. These technologies are focused in the following areas:

- Monitoring, filtering, and removing hazardous materials (e.g., chemicals like arsenic, bacteria like cryptosporidium, and organic compounds like algae and oil) from water used for drinking, farming, food processing and manufacturing.
- Development of methods and technologies used in the manufacturing processes of advanced materials, products, and pharmaceutical devices and therapies.
- Utilization in fuel production— refining of petroleum, manufacture of fuel cells and hydrogen gas, and development of biofuels, including ethanol and algae.
- Design of marine vessels and navigation technologies that improve efficiencies and reduce negative environmental impacts.
- Cultivation of drought-resistant and drought-tolerant plants.

THE URC'S PLACE IN WATER RESEARCH AND INNOVATION

There is a broad effort underway in Michigan and across the Great Lakes region to address issues of water quality and quantity at the community, state, and multi-state levels. These include multi-state and provincial cooperation through the Council of Great Lakes Governors, the Great Lakes Restoration Initiative, and countless collaborations among communities and universities in the region. It also includes university-level collaboration ranging from individual research

projects across universities to formal collaborations such as the Transborder Research University Network, in which eight Canadian and eight U.S. research universities (including all three URC universities) collaborate on research, pursue joint applications for funding, share university resources and facilities, and engage in the exchange of ideas through conferences, workshops, and student and faculty exchanges.

The knowledge and expertise generated through these efforts is helping, and will continue to help, solve problems and capture opportunities throughout the region, and provide a basis for leadership in addressing water-related issues nationally and globally. The URC universities often are working in coordination with colleagues from other Michigan universities, many of whom are leading valuable research centers in strategic locations around the state and conducting research that is contributing to greater understanding of water sustainability and restoration. URC university researchers are also connected with researchers across the Great Lakes Region, the nation, and the world through unique and targeted collaborations.

The URC-based research described in this section represents a significant contribution to this overall effort by universities, governments, private associations, and other stakeholders. URC contributions to multidisciplinary research in water monitoring and filtration, agriculture's relationship to water issues, and other areas are recognized as important contributions to the larger effort.

Appendix A. Data and Methodology

INDUSTRY SECTORS DIRECTLY RELATED TO WATER

We set out to identify a list of 4-digit NAICS industries that make up the most intensively water-related sectors of the economy. As noted in "Defining Industry Sectors Directly Related to Water" on page 7, we began with the question: "What industries most directly benefit from advancements in water-related research and innovation affecting water quality and quantity?"

Industries that directly provide water-related services such as consulting and analysis, directly provide wastewater and other water management services, or which manufacture equipment such as filtration media, were marked as CWPS industries. Industries noted for being users of large amounts of high quality water, or which are critical industries for controlling discharge or runoff into surface water systems were marked as WEI industries.

The industries selected were reviewed by university water researchers and industry experts to ensure each represented a reasonable inclusion in the overall picture of water-intensive industries.

See Table A-1 below for a list of included industries.

RESEARCH AWARD METHODOLOGY

To quantify the amount of research that is on "water-related" topics, we reviewed research awards data from the URC universities (including all University of Michigan campuses) for projects active from 2009-2013 at each URC university in collaboration with URC staff.

The search method was adapted from the model created by Don Scavia and his team at the University of Michigan's Graham Sustainability Institute, which is conducted on awards data each year. Adaptations for this report included the addition of key words identified in known water research at all three URC institutions, such as the term "ballast" referring to the water contained in the ballasts of ships that is a source for the transport of aquatic invasive species. Terms referring to climate and land policy were eliminated in order to focus on water specific research. Included was research on quality and quantity of water resources (e.g., lakes, streams, groundwater, rivers, wells, precipitation, public utilities) and monitoring and cleaning technologies (e.g., filters, modeling, wastewater and sewer management processes and technologies, non-point source pollution: urban and agricultural runoff management), health and vitality of water bodies (e.g., oceans, glaciers, Great Lakes, estuaries, wetlands, peat lands), indicators of ecosystem health (e.g., fisheries, pelagic birds, invasive aquatic species, marine mammals), and use of water research, manufacturing, and other processes.

In addition to a key word search, a review of all awards by identified water researchers across the URC was conducted to identify additional water-related

research not flagged in key word search. Finally, awards were reviewed by known water-focused funders. Two separate searches were conducted and reconciled through two rounds of comparisons of identified awards. The result is an estimate of water-related research across the URC over the past five years.

Our estimate for the amount of awards active during the period 2009-2013 includes projects that started before 2009 and others that were active after 2013. We allocated the amount of awards that "count" during this period as follows:

- First, we divided the total award amount by the estimated number of days between the start and end dates of the award listed in the data.
- We then estimated the number of days in each year from 2009-2013 that were between the project's start and end dates.
- We then multiplied the average daily amount of the award by the number of days during the target years for which the project was active.

This methodology is limited in that it does not account for any systematic variation in spending of research award amounts, such as a tenancy to spend down awards more heavily toward the beginning or end of the projects.

DEGREES IN WATER-RELATED FIELDS

We identified the following water-related degrees from the 2013 data in IPEDS for each school (including all University of Michigan campuses).

Bachelor's Degrees:

- Agricultural Public Services
- Biochemistry Biophysics and Molecular Biology
- Biological and Biomedical Sciences Other
- Biological and Physical Sciences
- Biology General
- Biomedical/Medical Engineering
- Botany/Plant Biology
- Cell/Cellular Biology and Anatomical Sciences
- Chemical Engineering
- Chemistry
- City/Urban Community and Regional Planning
- Civil Engineering
- Ecology Evolution Systematics and Population Biology
- Food Science and Technology
- Forestry
- Geography and Cartography
- Geological and Earth Sciences/Geosciences

- Geological/Geophysical Engineering
- Landscape Architecture
- Natural Resources Conservation and Research
- Natural Resources Management and Policy
- Naval Architecture and Marine Engineering
- Plant Sciences
- Wildlife and Wildlands Science and Management
- Zoology/Animal Biology

Master's Degrees

- Agricultural Engineering
- Atmospheric Sciences and Meteorology
- Biochemistry Biophysics and Molecular Biology
- Biological and Biomedical Sciences Other
- Biology General
- Biomathematics Bioinformatics and Computational Biology
- Biomedical/Medical Engineering
- Biotechnology
- Botany/Plant Biology
- Cell/Cellular Biology and Anatomical Sciences
- Chemical Engineering
- Chemistry
- City/Urban Community and Regional Planning
- Civil Engineering
- Ecology Evolution Systematics and Population Biology
- Environmental Design
- Environmental/Environmental Health Engineering
- Food Science and Technology
- Forestry
- Geography and Cartography
- Geological and Earth Sciences/Geosciences
- Landscape Architecture
- Natural Resources Conservation and Research
- Natural Resources Management and Policy
- Naval Architecture and Marine Engineering
- Plant Sciences
- Wildlife and Wildlands Science and Management
- Zoology/Animal Biology

Doctoral Degrees

- Agricultural Engineering
- Atmospheric Sciences and Meteorology
- Biochemistry Biophysics and Molecular Biology
- Biology General
- Biomathematics Bioinformatics and Computational Biology
- Biomedical/Medical Engineering
- Botany/Plant Biology
- Cell/Cellular Biology and Anatomical Sciences
- Chemical Engineering
- Chemistry
- City/Urban Community and Regional Planning
- Civil Engineering
- Ecology Evolution Systematics and Population Biology
- Environmental/Environmental Health Engineering
- Food Science and Technology
- Forestry
- Geography and Cartography
- Geological and Earth Sciences/Geosciences
- Natural Resources Conservation and Research
- Natural Resources Management and Policy
- Naval Architecture and Marine Engineering
- Plant Sciences
- Wildlife and Wildlands Science and Management
- Zoology/Animal Biology

Table A-1. Water Dependent Private Sector Employment in Michigan and the United States, 2012

NAICS	Industry Description	Michigan	United States
Core Water Products and Services			
3271	Clay Product and Refractory Manufacturing (Includes filtering media)	350	39,811
5413	Architectural, Engineering, and Related Services	68,257	1,318,177
5416	Management, Scientific, and Technical Consulting Services	25,661	1,127,739
5417	Scientific Research and Development Services	20,239	634,404
5419	Other Professional, Scientific, and Technical Services	16,995	608,251
5622	Waste Treatment and Disposal	3,617	95,328
5629	Remediation and Other Waste Management Services	2,907	125,094
Total		138,026	3,948,804
Water-Enabled Industries			
1111	Oilseed and Grain Farming	1,105	48,466
1112	Vegetable and Melon Farming	2,622	97,091
1113	Fruit and Tree Nut Farming	4,012	190,379
1114	Greenhouse, Nursery, and Floriculture Production	6,333	144,080
1119	Other Crop Farming	790	63,059
1121	Cattle Ranching and Farming	5,048	141,531
1122	Hog and Pig Farming	486	29,502
1123	Poultry and Egg Production	1,117	39,442
1124	Sheep and Goat Farming	51	1,333
1125	Aquaculture	8	5,745
1132	Forest Nurseries and Gathering of Forest Products	64	2,974
1133	Logging	1,489	48,874
1141	Fishing	77	6,424
1142	Hunting and Trapping	105	1,784
1151	Support Activities for Crop Production	1,712	305,784
2111	Oil and Gas Extraction	590	188,003
2121	Coal Mining	Not available	85,925
2122	Metal Ore Mining	Not available	44,418
2123	Nonmetallic Mineral Mining and Quarrying	2,050	87,718
2211	Electric Power Generation, Transmission and Distribution	16,360	393,366
2213	Water, Sewage and Other Systems	461	47,303
3111	Animal Food Manufacturing	356	52,455
3112	Grain and Oilseed Milling	4,744	60,123
3113	Sugar and Confectionery Product Manufacturing	1,837	68,308
3114	Fruit and Vegetable Preserving and Specialty Food Manufacturing	6,340	170,793
3115	Dairy Product Manufacturing	3,928	132,437
3116	Animal Slaughtering and Processing	6,067	482,350
3117	Seafood Product Preparation and Packaging	114	37,417
3118	Bakeries and Tortilla Manufacturing	6,228	282,541
3119	Other Food Manufacturing	3,148	173,423
3121	Beverage Manufacturing	5,246	177,236
3122	Tobacco Manufacturing	Not available	14,035
3131	Fiber, Yarn, and Thread Mills	70	28,140
3132	Fabric Mills	99	55,316
3133	Textile and Fabric Finishing and Fabric Coating Mills	405	34,477
3141	Textile Furnishings Mills	555	51,896
3149	Other Textile Product Mills	1,745	63,567
3151	Apparel Knitting Mills	Not available	14,145
3152	Cut and Sew Apparel Manufacturing	864	121,729
3159	Apparel Accessories and Other Apparel Manufacturing	60	12,436
3161	Leather and Hide Tanning and Finishing	248	3,987
3162	Footwear Manufacturing	Not available	13,623
3169	Other Leather and Allied Product Manufacturing	60	11,827
3211	Sawmills and Wood Preservation	1,710	83,859
3212	Veneer, Plywood, and Engineered Wood Product Manufacturing	2,121	62,569
3219	Other Wood Product Manufacturing	4,255	192,549
3221	Pulp, Paper, and Paperboard Mills	3,389	108,026
3222	Converted Paper Product Manufacturing	7,882	271,494
3231	Printing and Related Support Activities	14,055	459,148
3241	Petroleum and Coal Products Manufacturing	1,344	111,436

Table A-1. Water Dependent Private Sector Employment in Michigan and the United States, 2012 (Continued)

3251	Basic Chemical Manufacturing	2,337	143,104
3252	Resin, Synthetic Rubber, and Artificial Synthetic Fibers and Filaments Manufacturing	7,097	91,560
3253	Pesticide, Fertilizer, and Other Agricultural Chemical Manufacturing	694	36,539
3254	Pharmaceutical and Medicine Manufacturing	7,940	269,660
3255	Paint, Coating, and Adhesive Manufacturing	3,204	58,385
3256	Soap, Cleaning Compound, and Toilet Preparation Manufacturing	3,496	102,375
3259	Other Chemical Product and Preparation Manufacturing	3,568	83,866
3261	Plastics Product Manufacturing	29,702	515,233
3262	Rubber Product Manufacturing	4,533	129,583
3272	Glass and Glass Product Manufacturing	3,022	79,638
3273	Cement and Concrete Product Manufacturing	3,702	164,620
3274	Lime and Gypsum Product Manufacturing	216	14,102
3279	Other Nonmetallic Mineral Product Manufacturing	2,648	67,880
3311	Iron and Steel Mills and Ferroalloy Manufacturing	6,107	92,827
3312	Steel Product Manufacturing from Purchased Steel	1,604	58,707
3313	Alumina and Aluminum Production and Processing	1,807	57,640
3314	Nonferrous Metal (except Aluminum) Production and Processing	1,366	62,300
3315	Foundries	10,489	128,507
3321	Forging and Stamping	7,241	98,481
3322	Cutlery and Handtool Manufacturing	1,244	39,343
3323	Architectural and Structural Metals Manufacturing	10,575	341,636
3324	Boiler, Tank, and Shipping Container Manufacturing	1,559	95,147
3325	Hardware Manufacturing	1,509	23,264
3326	Spring and Wire Product Manufacturing	2,712	41,685
3327	Machine Shops; Turned Product; and Screw, Nut, and Bolt Manufacturing	27,761	360,426
3328	Coating, Engraving, Heat Treating, and Allied Activities	13,777	135,512
3329	Other Fabricated Metal Product Manufacturing	9,424	268,709
3331	Agriculture, Construction, and Mining Machinery Manufacturing	2,431	246,799
3332	Industrial Machinery Manufacturing	5,360	104,607
3333	Commercial and Service Industry Machinery Manufacturing	1,875	89,371
3334	Ventilation, Heating, Air-Conditioning, and Commercial Refrigeration Equipment Manufacturing	3,467	126,256
3335	Metalworking Machinery Manufacturing	35,272	177,338
3336	Engine, Turbine, and Power Transmission Equipment Manufacturing	4,210	101,580
3339	Other General Purpose Machinery Manufacturing	13,481	251,789
3341	Computer and Peripheral Equipment Manufacturing	507	157,703
3342	Communications Equipment Manufacturing	611	109,671
3343	Audio and Video Equipment Manufacturing	229	20,316
3344	Semiconductor and Other Electronic Component Manufacturing	7,707	382,700
3345	Navigational, Measuring, Electromedical, and Control Instruments Manufacturing	8,199	400,066
3346	Manufacturing and Reproducing Magnetic and Optical Media	864	20,335
3351	Electric Lighting Equipment Manufacturing	521	46,013
3352	Household Appliance Manufacturing	5,234	56,676
3353	Electrical Equipment Manufacturing	2,421	143,108
3359	Other Electrical Equipment and Component Manufacturing	2,761	126,928
3361	Motor Vehicle Manufacturing	39,789	173,169
3362	Motor Vehicle Body and Trailer Manufacturing	6,424	126,806
3363	Motor Vehicle Parts Manufacturing	103,956	483,686
3364	Aerospace Product and Parts Manufacturing	3,758	494,975
3365	Railroad Rolling Stock Manufacturing	Not available	24,095
3366	Ship and Boat Building	1,319	128,350
3369	Other Transportation Equipment Manufacturing	Not available	32,675
3371	Household and Institutional Furniture and Kitchen Cabinet Manufacturing	4,470	217,729
3372	Office Furniture (including Fixtures) Manufacturing	14,563	98,230
3379	Other Furniture Related Product Manufacturing	545	34,843
3391	Medical Equipment and Supplies Manufacturing	11,269	307,540
3399	Other Miscellaneous Manufacturing	6,606	269,712
4831	Deep Sea, Coastal, and Great Lakes Water Transportation	685	39,053
4832	Inland Water Transportation	48	25,719
Total		579,266	13,903,110
Water Dependent Industries Total		717,292	17,851,914

Source: U.S Bureau of Labor Statistics
Analysis: Anderson Economic Group LLC

Table A-2 Estimate of Water-Related Employment as a Percentage of Total Employment, 2012

	Employment				Percentage of Total Employment			Ranking of 50 States		
State	Core Water Products and Services	Water Enabled Industries	Total Water Related Industries	Total Employment	Core Water Products and Services	Water Enabled Industries	Total Water Related Industries	Core Water Products and Services	Water Enabled	Total Water Related
Indiana	49,716	513,532	562,412	2,418,425	2.1%	21.2%	23.3%	46	1	1
Wisconsin	49,621	487,828	537,295	2,315,717	2.1%	21.1%	23.2%	45	2	2
Alabama	49,906	275,016	323,944	1,467,367	3.4%	18.7%	22.1%	17	4	3
Michigan	**138,026**	**581,028**	**718,704**	**3,373,672**	**4.1%**	**17.2%**	**21.3%**	**10**	**8**	**4**
Idaho	21,205	82,802	103,989	503,774	4.2%	16.4%	20.6%	9	10	5
Iowa	20,279	235,424	255,509	1,241,299	1.6%	19.0%	20.6%	50	3	6
Arkansas	17,733	176,498	193,857	944,388	1.9%	18.7%	20.5%	47	6	7
Mississippi	14,808	158,503	173,110	846,759	1.7%	18.7%	20.4%	48	5	8
Kansas	32,957	183,102	215,783	1,076,065	3.1%	17.0%	20.1%	24	9	9
Washington	93,785	379,353	472,879	2,378,502	3.9%	15.9%	19.9%	12	14	10
South Carolina	49,577	242,647	291,145	1,478,136	3.4%	16.4%	19.7%	18	11	11
Kentucky	34,987	251,021	285,229	1,455,758	2.4%	17.2%	19.6%	43	7	12
Oregon	39,871	220,070	259,480	1,372,310	2.9%	16.0%	18.9%	28	12	13
Ohio	117,798	693,528	806,596	4,337,301	2.7%	16.0%	18.6%	32	13	14
North Carolina	106,933	479,442	584,545	3,226,792	3.3%	14.9%	18.1%	20	16	15
California	571,542	1,685,345	2,254,208	12,684,429	4.5%	13.3%	17.8%	7	24	**16**
Minnesota	55,795	341,571	397,191	2,276,259	2.5%	15.0%	17.4%	40	15	17
Vermont	6,666	36,570	42,963	247,087	2.7%	14.8%	17.4%	34	17	18
Tennessee	62,213	328,483	389,182	2,240,924	2.8%	14.7%	17.4%	31	18	19
Oklahoma	32,926	177,847	209,439	1,222,393	2.7%	14.5%	17.1%	35	19	20
Nebraska	21,598	108,136	129,494	762,468	2.8%	14.2%	17.0%	29	22	21
West Virginia	14,040	81,154	94,057	567,438	2.5%	14.3%	16.6%	39	21	22
Illinois	173,711	627,182	799,806	4,843,785	3.6%	12.9%	16.5%	15	26	23
Utah	36,120	129,884	165,760	1,006,278	3.6%	12.9%	16.5%	14	27	24
South Dakota	5,668	47,785	53,442	329,141	1.7%	14.5%	16.2%	49	20	25
Pennsylvania	167,199	625,434	790,039	4,887,296	3.4%	12.8%	16.2%	16	28	26
Wyoming	6,204	28,065	34,269	212,192	2.9%	13.2%	16.1%	27	25	27
New Hampshire	13,856	70,157	83,931	527,252	2.6%	13.3%	15.9%	36	23	28
Texas	340,438	1,070,597	1,406,689	8,964,789	3.8%	11.9%	15.7%	13	32	29
Connecticut	39,389	175,765	215,094	1,391,749	2.8%	12.6%	15.5%	30	29	30
Georgia	93,683	396,240	488,115	3,190,572	2.9%	12.4%	15.3%	26	31	31
Virginia	179,430	260,368	439,283	2,927,218	6.1%	8.9%	15.0%	3	40	32
New Mexico	39,667	50,566	90,121	603,114	6.6%	8.4%	14.9%	1	43	33
Missouri	55,517	271,957	326,734	2,188,757	2.5%	12.4%	14.9%	38	30	34
Louisiana	49,253	179,218	228,228	1,540,332	3.2%	11.6%	14.8%	22	34	35
Maine	12,702	58,046	70,612	486,542	2.6%	11.9%	14.5%	37	33	36
Alaska	11,533	24,541	36,074	248,576	4.6%	9.9%	14.5%	6	37	37
Massachusetts	145,612	265,125	409,840	2,828,275	5.1%	9.4%	14.5%	4	39	38
Colorado	93,836	167,208	259,744	1,891,870	5.0%	8.8%	13.7%	5	41	39
Arizona	63,034	200,849	263,615	2,045,349	3.1%	9.8%	12.9%	23	38	40
Rhode Island	8,630	41,059	49,689	392,112	2.2%	10.5%	12.7%	44	35	41
North Dakota	8,439	34,951	43,332	344,538	2.4%	10.1%	12.6%	41	36	42
Delaware	14,657	28,776	43,427	345,329	4.2%	8.3%	12.6%	8	45	43
New Jersey	130,290	266,462	395,733	3,194,470	4.1%	8.3%	12.4%	11	44	44
Maryland	125,733	125,017	250,064	2,024,063	6.2%	6.2%	12.4%	2	48	45
Montana	10,223	29,803	40,007	347,922	2.9%	8.6%	11.5%	25	42	46
New York	229,917	514,542	741,212	7,190,226	3.2%	7.2%	10.3%	21	46	47
Florida	211,617	432,910	644,089	6,312,193	3.4%	6.9%	10.2%	19	47	48
Nevada	23,996	56,120	80,116	988,141	2.4%	5.7%	8.1%	42	49	49
Hawaii	13,116	22,992	36,085	483,782	2.7%	4.8%	7.5%	33	50	50
United States	3,948,804	13,942,918	17,851,911	110,645,869	3.6%	12.6%	16.1%			

Note: State totals may not sum to US figure due to suppressed data and the exclusion of outlying US posessions

*Where available, for suppressed 2012 data, 2011 BLS Quarterly Census of Employment and Wages or 2011 US Census Bureau County Business Pattens were used.

Source: Bureau of Labor Statistics Quarterly Census of Employment and Wages 2012 Data; Analysis by Anderson Economic Group*
Analysis: Anderson Economic Group

Appendix B. Summary of Past URC Sector Reports

In 2013 the URC commissioned a study exploring the impact alumni entrepreneurs of MSU, U-M, and WSU have on the Michigan, U.S. and global economies. The URC has also commissioned annual industry sector reports. Key findings from those reports include:

ALUMNI ENTREPRENEURSHIP (2013)

- URC alumni entrepreneurs started or acquired businesses at double the national average rate among college graduates since 1996.
- 50% of the companies created by URC entrepreneurs are located in Michigan with the rest in every other state and more than 100 different countries.
- Compared to the most recently available five-year success rate for U.S. firms, URC alumni-started firms were nearly 1.5 times more likely to remain in operation.
- Most URC entrepreneurs start a business in an area outside their major areas of study.

AUTOMOTIVE INNOVATION (2012)

- The URC universities supply talented workers to the auto industry, conferring more than 3,600 degrees annually in auto-ready disciplines.
- URC universities play a direct role in auto industry innovation by spending $60 million annually of their R&D dollars on auto-related research and development.
- Between FY 2007 and 2011, the URC universities spent $300 million on over 1,400 auto projects. Nearly two-thirds of this research was funded by federal and state governmental agencies.
- Private industry funded 28 percent of all auto research at the URC universities in the past five years, which is nine times the average share of industry funding for all university R&D at these institutions.
- URC researchers have helped automakers improve vehicle quality and safety, improve engine efficiency and performance, and reduce fossil fuel use through new auto approaches. Specific examples include:
    - The 2mm project that involved U-M and WSU that limited and controlled the gaps between auto components;
    - The connected vehicle research at U-M and WSU that promises improved safety by allowing vehicles to “talk” to one another and the infrastructure;
    - Biofuels research that is currently being done by MSU on new types of feedstock that can be grown more economically to lower fuel costs and improve fuel efficiency.

INFORMATION AND COMMUNICATION TECHNOLOGY (2011)

- The URC universities spent nearly $74 million on research projects with a strong IT focus in FY2010.
- Of the nearly 150 start-ups the URC has assisted in creating since 2001, approximately 40 percent have had a distinct ICT component.
- Information technology employs about 3.5 percent of the state's workforce, or about 135,000 workers, and is significant not only as its own sector but as the underpinning for much of the major industry activity and growth represented in previous sector reports.
- The industry pays high wages, with employees earning about $20,000 more than other workers in the private sector.

ADVANCED MANUFACTURING (2010)

- Michigan's advanced manufacturing industry employs 381,351 workers, accounting for 10.3 percent of all employment (2007 data). Fully one-third of advanced manufacturing jobs in the Midwest are in Michigan.
- The average wage in the advanced manufacturing industry was $64,122.
- URC universities spent $101 million on advanced manufacturing R&D in 2009.
- URC universities are educating more than 14,000 students in engineering.

LIFE SCIENCES (2009)

- Michigan's life sciences industry employed more than 79,000 workers, accounting for 2.1 percent of all employment (2006 data).
- Between 1999 and 2006, life sciences industry employment grew by 10.7 percent while during that same time period manufacturing employment dropped by 24 percent.
- Life sciences wages averaged $83,494 in 2006.
- In 2008, URC universities spent $887 million on life sciences research and development.
- R&D expenditures grew 69 percent since the founding of the Life Sciences Corridor in 1999.

ALTERNATIVE ENERGY RESEARCH AND DEVELOPMENT (2008)

- Michigan has a comparative advantage in biomass and wind compared to the energy potential in the other 49 states.
- URC universities spent more than $79.5 million on R&D related to alternative energy in 2007.
- Federal funding provided 71 percent ($56.8 million) of total R&D funding in alternative energy.
- More than 50 percent of all alternative energy R&D supported the auto industry.

Appendix C. About the Author

ANDERSON ECONOMIC GROUP

Anderson Economic Group, LLC is a research and consulting firm specializing in economics, public policy, finance and business valuation, and market and industry analysis. The firm has offices in Chicago, Illinois and East Lansing, Michigan. AEG has conducted economic and fiscal impact studies for private, public, and non-profit clients across the United States.

Since 2007, AEG has completed two annual studies for the University Research Corridor. The first report is an assessment of the URC's economic impact on the state of Michigan, which is released every fall or winter. The second report is an assessment of how the URC universities contribute to an important economic sector in the state, which is released every spring. For past reports and more information on AEG, visit www.AndersonEconomicGroup.com.

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Mr. Rosaen's recent work includes several economic and fiscal impact analyses, including of proposed real estate developments, power plants, and infrastructure projects; analysis of tax incentives; an analysis of the impact of federal tax incentives on the freight rail industry; and an analysis of the economic contribution that research universities make in the State of Michigan.

Prior to joining Anderson Economic Group, Mr. Rosaen worked for the Office of Retirement Services (part of the Michigan Department of Management and Budget) for the Benefit Plan Design group. He has also worked as a mechanical engineer for Williams International in Walled Lake, Michigan.

Mr. Rosaen holds a Masters in Public Policy from the Gerald R. Ford School of Public Policy at the University of Michigan. He also has a Masters of Science and a Bachelors of Science in mechanical engineering from the University of Michigan.