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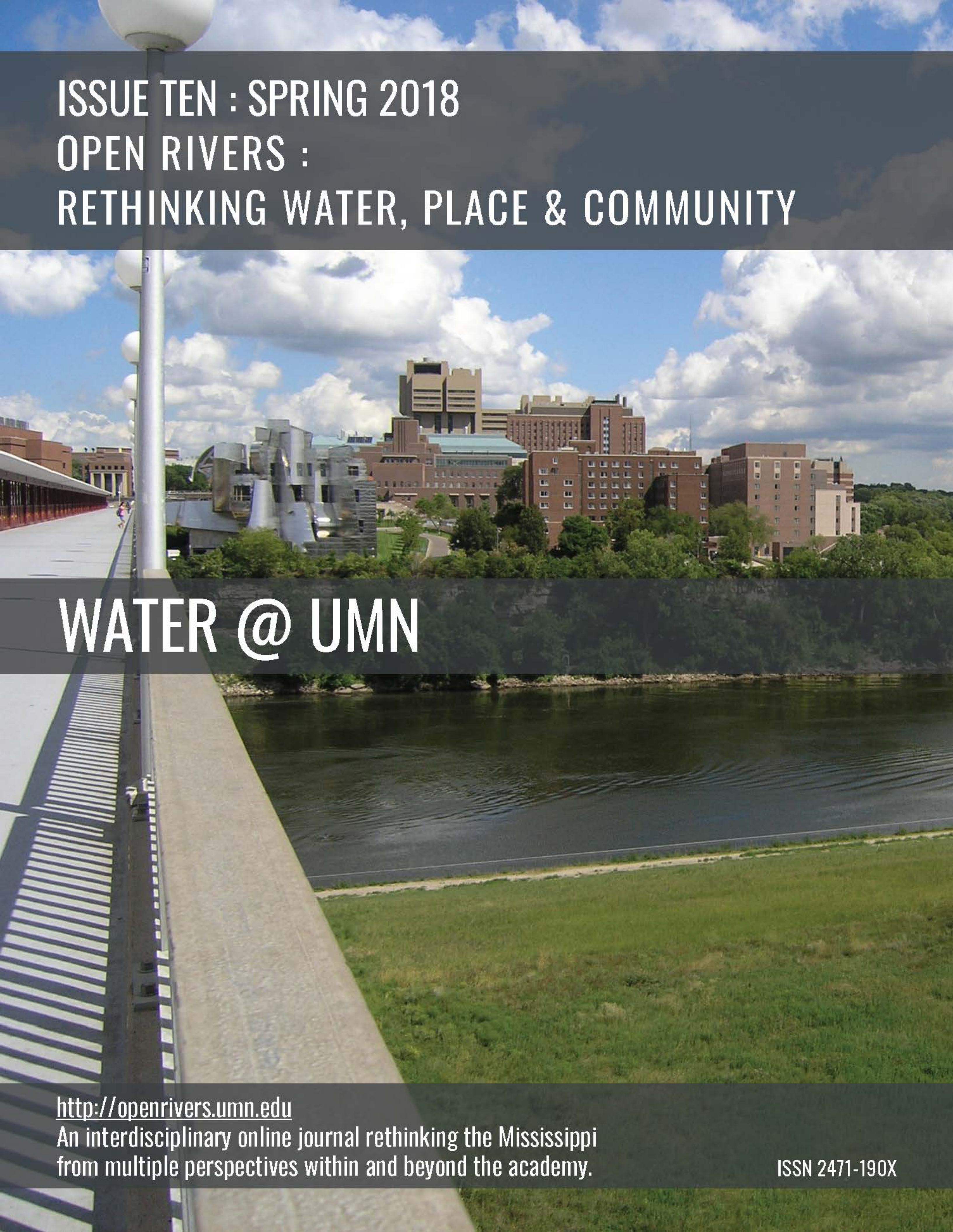

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The cover image is of The East Bank of the Minneapolis campus of the University of Minnesota and the Mississippi River from the Washington Avenue Bridge. Image courtesy of Patrick Nunnally.

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Editorial Board

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FEATURE

THE FUTURE OF AGRICULTURE IN A WATER-RICH STATE

By Ann Lewandowski, Axel Garcia y Garcia, Chris Lenhart, David Mulla, Amit Pradhananga, and Jeff Strock

In 1920, Minnesota held 2.4 million people and 132,744 farms. Corn production was near 100 million bushels per year. By 1929, 18.5 million acres were under cultivation. Nearly 100 years later, the state has 5.4 million people, 74,500 farms, and 26 million acres of farmland. Annual production of corn is about 1.5 billion bushels and soybean is about 380 million bushels.

Over that century, agricultural technology and infrastructure changed profoundly. Equally transformed are the threats to streams, lakes, and

Protecting water quality requires integrated thinking about agricultural "working lands" and conservation. Image courtesy of David Hansen.

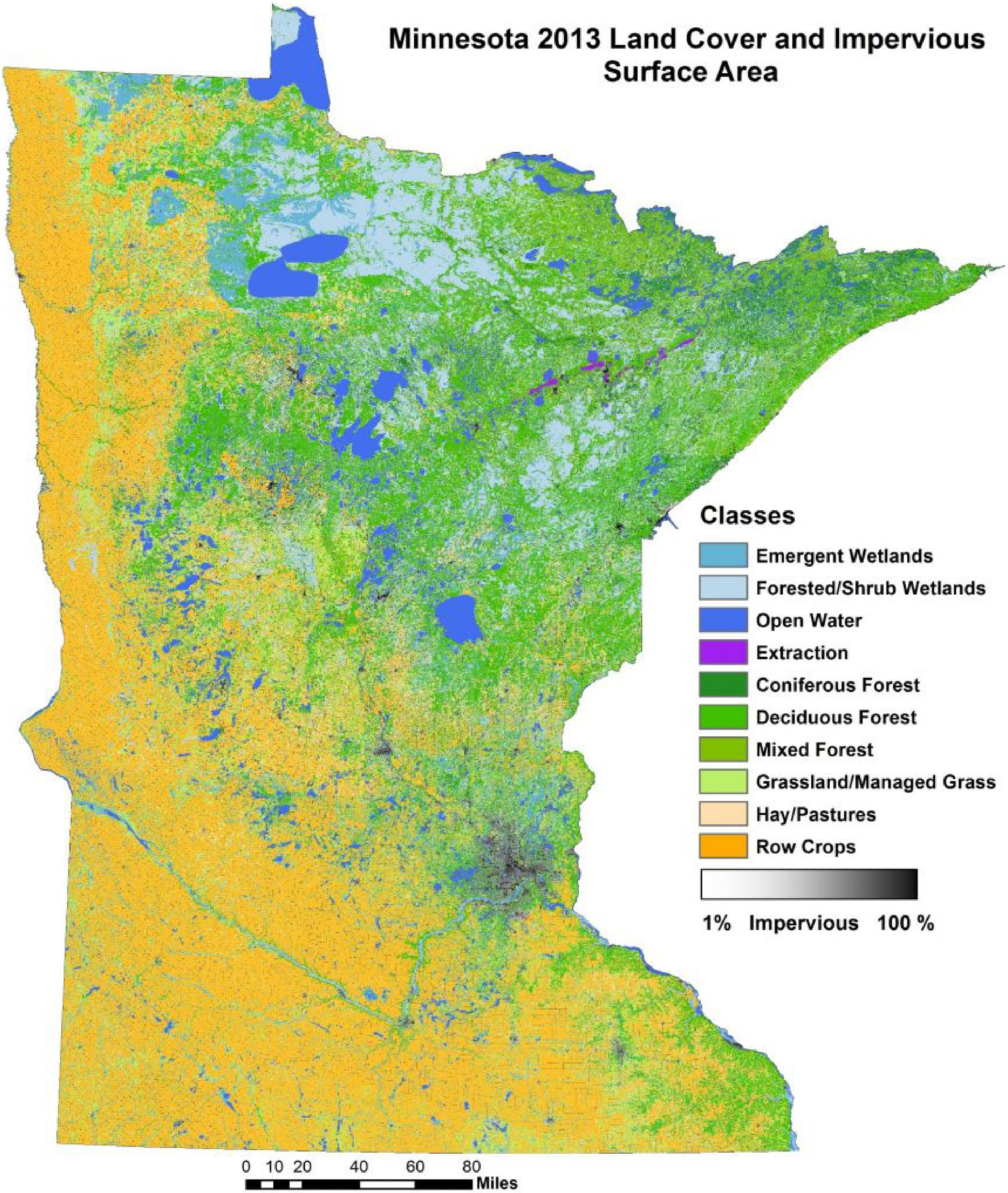
drinking water. Population, urbanization, and chemical production and use have exploded. The result is a growing tension between agriculture and water quality. Hydrology—where rainfall flows and pauses on the landscape—has also changed dramatically. In this new context, protecting a healthy future for both agriculture and water requires deliberate work from both the agricultural community and the university research community. This article is about the cutting edge work at the University of Minnesota (UMN) that is helping transform farming and water resource management.

Water runs through all our land and vegetation; it cannot be protected adequately by simply setting aside key refuges. We also need "working lands conservation" where we manage water quality and habitat in concert with farming. Half the land in Minnesota is managed by farmers, most as cropland, but interlaced with grazing land, woodland, stream buffers, farmsteads, and so on. For this reason, it is essential that farmers and non-farmers equally participate in the water conversation. Farmers are essential because they directly manage the land and bear much of the costs and benefits. Non-farmers are important because they also influence land management, benefit from the agricultural economy, and help pay for water management. Participating in the conversation means learning about unfamiliar topics, including how farmers farm and why, how climate is shifting, the unique character of Minnesota landscapes and soils, the impacts of urban development, and how individuals and communities make choices that impact water. All of those topics influence how we manage contamination of drinking water, algae-choked ponds, sedimentation of Lake Pepin, the hypoxic zone in the Gulf of Mexico, small-scale flooding and ponding, and more.

At the University of Minnesota, faculty and students in several colleges and countless departments are studying agriculture and its relationship to water. This article will highlight some of that work and what it means for agriculture in the next decade or two.

First, we want to highlight the work being done across rural Minnesota. Throughout the agricultural community, many individuals, businesses, and organizations are proactive and creative in finding ways to strengthen the sector while preserving the water and land resources they depend on. For example, the agricultural co-ops, equipment suppliers, private agronomists, and other professionals who guide farmers' decisions are increasingly providing conservation services. They are designing stream buffers and water detention structures; advising on cover crop mixes; analyzing detailed soil, pest, and crop data; and more. The implementation of the 2015 Minnesota Buffer Law highlighted examples of poor stream edge management, but also demonstrated that most streams were already protected. For decades, many farmers have been using water-friendly practices, including reduced tillage, grassed waterways, stream and ditch buffers, and fertilizer and manure management best practices. Hundreds of farmers have attended Nitrogen Smart training, a UMN Extension program supported by agricultural commodity organizations to improve the agronomic and environmental effectiveness of farmers' nitrogen management strategies. Major agricultural organizations are providing significant research funding and are collaborating with agencies and market-based initiatives to make Minnesota agriculture more water-friendly.

The remainder of this article will introduce a small sampling of the many agricultural research efforts around UMN, most of which rely on the support and engagement of individual farmers and agricultural organizations. We highlight four key trends that are transforming the relationship between food production and water resources.



More than half of Minnesota's land area is managed by farmers. Based on 2013 Landsat data. Image courtesy of Remote Sensing and Geospatial Analysis Laboratory, University of Minnesota.

These are arenas of opportunities for more productive agriculture and healthier water.

1. Minnesota hydrology is changing, and has been changing dramatically for decades. UMN researchers are studying how to respond to these shifts by developing practices to strategically store and retain more water on the landscape.

2. Cropping systems are the interdependent package of crops and management practices. UMN researchers are developing new cropping systems aimed at improving farmers' bottom line and risk management while improving agriculture's impact on water.

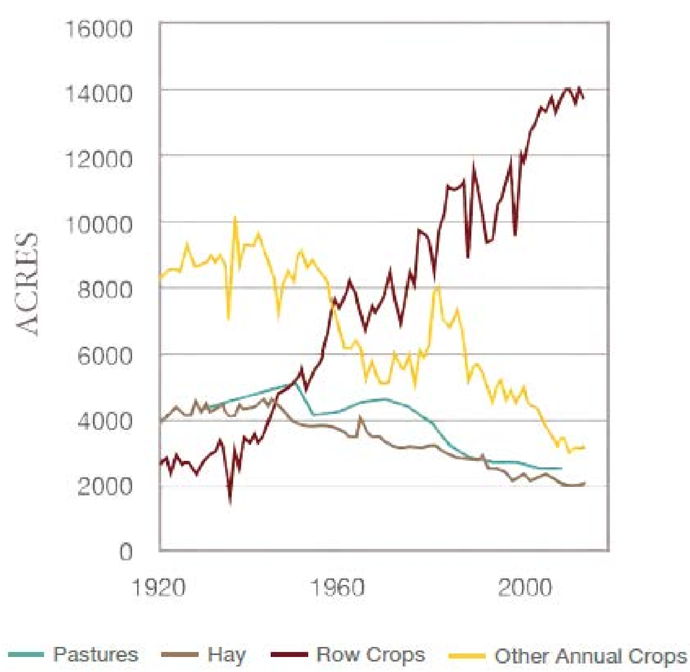
3. Robots, big data management, and other cutting-edge technologies have moved into rural Minnesota in a big way and are changing the look of agriculture, conservation work, and job opportunities.

4. In the end, managing water is about managing people. UMN researchers are active in addressing this people puzzle and changing how we frame water problems and solutions.

For this discussion, we are focusing on Minnesota, even though we are directly linked to global food supply and water issues (e.g., see Foley et al. 2011). We are also leaving many important themes for a future discussion, including the growing prominence of water quantity concerns in the face of irrigation demands and climate change, and increasing demand on groundwater aquifers and contamination of them.

Changing How Water Flows

The water cycle is often seen as an unchanging feature of the natural world, yet Minnesota has experienced dramatic changes to streamflow and rainfall amounts over the past few decades. The causes of these changes have been the subject of, at times, intense debate. We know that changing climate, land-cover and agricultural drainage have all contributed to increases in streamflow—both at small local scales and large river basin scales. Streamflow increases have been especially large in southern and western Minnesota streams and rivers. Some rivers have had a doubling of the average yearly flow since 1980, including the Yellow Medicine and Des Moines Rivers (Lenhart et al. 2011). These increased flow levels have led to greater rates of stream bank and bluff erosion with some rivers widening by as much as 50 percent compared to the widths observed in 1938 aerial photos (Lenhart et al. 2013). Some researchers (e.g., Gupta et al. 2015) have demonstrated that streamflow increases can be attributed primarily to climate change, as



Agricultural land cover has shifted dramatically over the past hundred years. Source: L. Schmitt-Olabisi. Image courtesy of Ann Lewandowski.

we've had increased annual rainfall and a greater frequency of large (greater than 2 inches per day) rainfall events. At the same time, agricultural drainage (ditches and subsurface tile) has expanded and intensified, and agricultural land cover has shifted dramatically away from pasture, hay crops, and small grains to corn and soybean. Both the changes in agricultural drainage and land cover tend to promote greater water yield from fields and increased annual flow to streams (even while subsurface drainage can reduce or slow flow of water after some rain events).

While the linkage between agricultural management practices and field erosion or nutrient export are fairly well established, the influence of agricultural management practices on farm- and landscape-scale water budgets remains poorly understood. The topic of agricultural drainage generates lively debate about the agronomic, environmental, and hydrologic impacts of drainage. The supporters emphasize the potential benefits of increased crop growth and productivity, reduced risk of crop loss from excess water stress, earlier planting, reduced crop susceptibility to pests and disease, reduced sediment and phosphorus in runoff, and the addition of soil water storage. In contrast, detractors of agricultural drainage tend to focus on the loss of wetlands, hydrologic alteration, and loss of soil nitrate to

A three-cell treatment wetland on a Martin county farm removes nitrogen and phosphorus from tile drainage before it flows into Elm Creek. Image courtesy of David Hansen.

surface and groundwater. The processes and mechanisms that control the volume and quality of drainage water leaving agricultural land is very complex. Land use, manure and nutrient management practices, drainage system design, antecedent soil moisture, soil properties, climate, rainfall intensity, watershed size, the location of drainage improvements in relation to the point of impact assessment, and characteristics of the pollutants are involved in complex interactions that impact water quantity and quality (Drury et al. 1996; Skaggs et al. 1994; Wesström et al. 2004; Zucker and Brown 1998).

Jeff Strock with Joe Magner and PhD student Lu Zhang are conducting research at the UMN Southwest Research and Outreach Center to better understand the role of agriculture and subsurface tile drainage in the observed changes to streamflow. Accurately identifying the relative contribution of agricultural management practices to basin-scale changes in hydrology is challenging because year-to-year weather variability can be much greater than the relatively small changes expected from changes in agricultural management, and further impacted by longer-term climate trends. Using a combination

A storage pond on a western Minnesota farm collects tile runoff in the spring to be used for supplemental irrigation during summer dry spells. Image courtesy of Jake Hicks.

of field research and systems analysis (modeling), Strock et al. (2014) designed an ongoing research project to quantify the water balances of corn production systems, with and without the presence of subsurface drainage, along a precipitation gradient from eastern South Dakota to south central Minnesota. Understanding the hydrologic response of drainage and crop water consumption at both the field and watershed scale will help corn growers be economically competitive, while also informing development of tools and management approaches that can minimize their environmental impact. Results from this work will provide important information to enable farmers to design water management infrastructure that is effective for crop production and environmentally responsible. Further, results from this work are expected to provide insight into the linkage between field-scale management decisions and watershed-scale hydrologic responses.

More information about this work in Minnesota and other states can be found at https://transformingdrainage.org/.

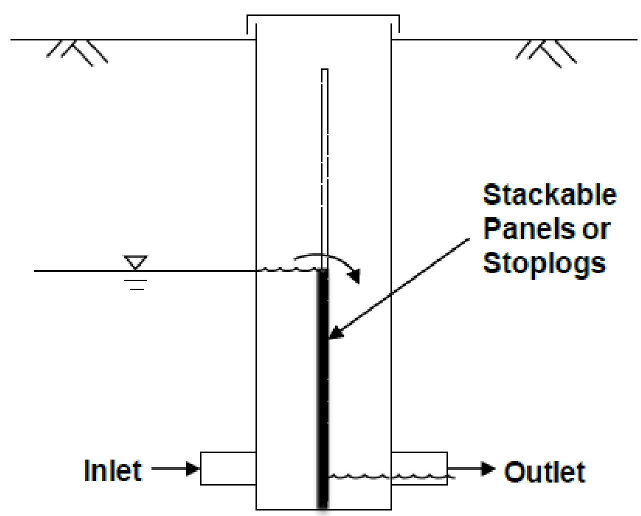
On a farm next to the Cottonwood River, patterned drainage tile is installed with drainage control structures that allow a farmer to raise the water level for parts of the year when a higher water table does not restrict crop growth or field operations. Image courtesy of Jeffrey Strock.

While the debate continues over the relative importance of historical causes of increasing streamflow, there is widespread agreement that we need to better manage the water on our landscape to reduce downstream erosion and pollutant loading. This can be accomplished by slowing water down as it moves through a watershed, by building water and sediment ponds or restoring wetlands. This surface water storage is proven to reduce downstream flows, but it is impractical to restore large areas of wetlands, given the high value of farmland, particularly in southern and western Minnesota. We need alternative water storage practices, as well as better drainage water management approaches. Research into alternative wetland design has been done by PhD student Brad Gordon with Chris Lenhart and Dean Current, with funding from Minnesota Department of Agriculture (Lenhart et al. 2016). In Martin County, an edge-of-field tile drainage treatment wetland was built and successfully incorporated into a farming system and continues to remove nitrogen and phosphorus from entering Elm Creek. The project shows that small constructed wetlands can help address some of our water management problems, but are insufficient alone.

Another approach to reducing flow is the use of drainage water management where water control structures are used to manage water levels in tile drain outlets to reduce outflow from fields in the winter or spring when soil drainage is not necessary for crop growth. On-farm research conducted by Jeff Strock at the Nettiewyynnt Farm in western Redwood County, a fifth-generation farm owned and operated by Brian and Michelle Hicks, showed an annual average reduction in nitrate loss of 24 percent when using controlled drainage compared to conventional free-drainage between 2006 and 2014.

While we can't go backwards in time to a pre-development landscape of abundant wetlands across southern and western Minnesota, we can mimic the functions of wetlands and prairie grasses by working with farmers to strategically place management practices in the landscape. Towards that end, numerous management practice placement tools have been developed. For example, Dave Mulla, Jake Galzki, and others developed a tool to help farmers select alternative practices to provide equivalent water quality treatment as riparian buffers (MN Corn Growers 2017). In the long term, the technical challenges can be met, but it is the adoption of these management practices by landowners and alignment of economics with environmental values that will be key for success.

The examples above address hydrology at several points on the landscape, including the stream edge and floodplains, water storage features, edge-of-field water management features, and in-field drainage water management. The final piece of this puzzle is in-field crop and soil management—practices that impact what happens when rainfall first hits the land. The importance of vegetation and related research is discussed in the next section on "Innovations in Cropping Systems." In addition, the Office for Soil Health was recently created by the UMN Water Resources Center and the MN Board of Water



Schematic of the controlled drainage concept, using an in-field water control structure. Diagram courtesy of Jeffrey Strock.

and Soil Resources. The goal of MOSH is to strengthen the university's work in understanding and communicating how farming practices impact soil organic matter and other soil characteristics that determine how much water enters into the soil and is stored in it. The arena of soil health is widely seen as a "win-win" for agriculture and the environment, helping farmers improve the productivity of their soil while improving water quality in the streams, lakes, and wetlands receiving drainage from farmland.

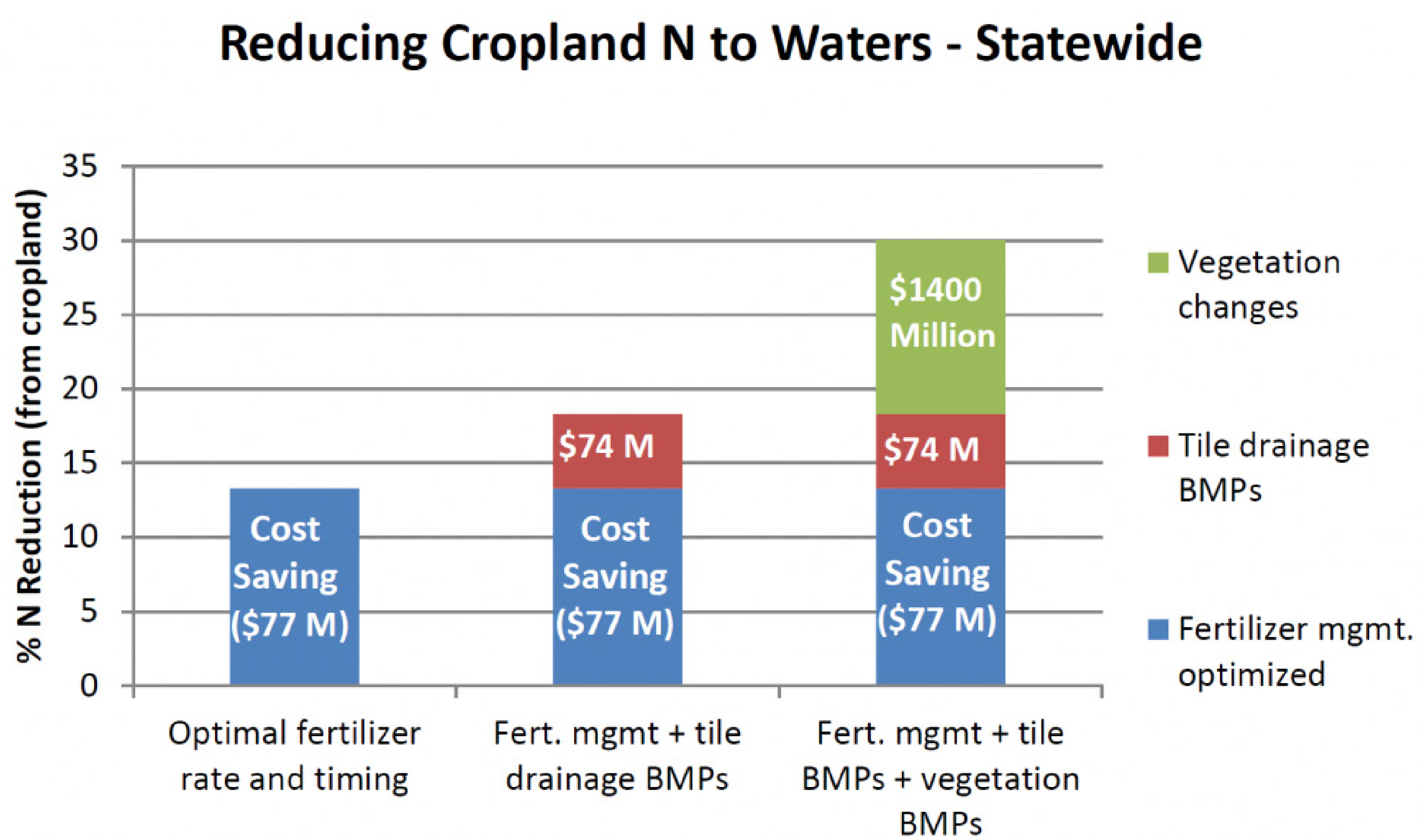
More about hydrology in rural Minnesota is explained in the UMN publication, *Fields to Streams*. Part 1 explains how land management, climate, geography, and drainage affect the water cycle and stream changes. Part 2 describes the agricultural land management practices that impact hydrology.

Double cropping with camelina at the Southwest Research and Outreach Center at Lamberton. "Relay crops" are planted before the first crop is harvested. "Sequence crops" are planted after the first crop is harvested. Image courtesy of Axel Garcia y Garcia.

Innovations in Cropping Systems

Minnesota cropland is a story of contrasts. Some of the most productive soils in the world are found here, yet our featured crop commodities are necessarily produced with high external inputs (e.g., fertilizer, crop protection chemicals, and direct energy). Our weather is highly variable and winters are extremely cold and long, but annual crops are grown successfully. We are famous for our quantity of fresh water, but water quality problems threaten human health, society's recreational places, and the ecosystems. Both water and nutrients are fundamental to crop yield increases, but many of our water resources (rivers, streams, and lakes) are reported to have quality impairments due to nitrogen, phosphorus, and sediments. Notable improvements have been made to reduce nonpoint source pollution related to agriculture, but more progress is needed to achieve Clean Water Act goals of fishable and swimmable waters, and the Minnesota Nutrient Reduction Strategy goal of 45 percent reduction in nitrates by 2045.

Cropping systems are managed ecosystems; as such, options to reduce negative impacts to the environment should be part of that management. For example, soil health, pests, and diseases must be integrated into a systems approach for



Nitrogen fertilizer management is important, but will not be enough to reach the state's nitrogen reduction goal of 45%. Current innovations will dramatically reduce the cost of vegetation BMPs such as cover crops and double cropping.
MPCA. 2013. Nitrogen in Minnesota Surface Waters. Page F1-18.

sustainable management, because in the end, cropping systems will be as sustainable as their capacity to provide environmental benefits like clean water.

With few exceptions, most cropping practices directly or indirectly impact the quantity and quality of water. Mainstream agriculture is based on mono-cropping utilizing practices like tillage, heavy use of synthetic fertilizers, and dependence on pesticides. Environmental pollution and its association with human health issues are the major concerns of this approach, but arguably, it has fed our hungry world. Crop production in temperate and humid regions like Minnesota is extremely complex. Water impairment is of major concern due to the delicate balance among water resources and societal interests. The prospects of climate change in the region bring further challenges to this complexity. Rivers, the natural link between crop fields and the different destinations of water, along with a network of thousands of miles of ditch and tile drainage, ultimately expand the water quality issues to a society that is more aware and concerned about the environmental impacts of current cropping practices than ever before. The question, though, is whether twenty-first century cropping systems can protect our water resources for generations to come.

The importance of a systems approach.

Agricultural research is conducted using both reductionist and systems approaches. The former separates the system into its individual components so they can be analyzed separately. The latter uses the whole system so the complex interactions between components are analyzed. Commonly, systems approach-based production has been the realm of smaller and niche farming operations; however, technological innovations, including the development of sustainable cropping systems, remote sensing, and big data science, is opening the doors for large-scale agriculture to embrace a systems approach, as well. Regardless of the size of the enterprise, the prospect of a widespread systems approach is great news for sustainable production and a cleaner environment. In fact, options to reduce water quality impairments will not succeed if we do not understand the whole system.

Research at the University of Minnesota has explored two different approaches to systems-based intensification of agriculture: 1) Sustainable intensification, a concept based on increasing productivity from existing land with minimum environmental disturbance, which loosely characterizes the practices of mainstream and larger scale agriculture, and 2) Agroecological intensification, a concept based on ecological principles to reduce the use of external inputs (usually associated with the reduction in water quality), while increasing productivity, which loosely characterizes smallholder and organic producers. In both cases, the challenge is not simple: increase production in the same or less farmland while enhancing the quality of the environment, in which water plays an essential role. Our research efforts on diversified cropping systems have been gaining attention, in particular the Forever Green Initiative (FGI), which advocates for a greener landscape in the region through crop diversification and cropping practices that include the integration of cover crops and promote soil health. Should the concept of the FGI work, gains in the quality of water and the environment as a whole could be immense for the state and the region. More on the FGI work can be found at www.forevergreen.umn.edu, as well as in Issue Six of *Open Rivers*.

Promising technologies.

Options for a more diversified agriculture in the region include expanding our crop portfolio with winter annual oilseed, perennial cereals, and cover crops. Winter annual oilseed crops allow producing two crops in one year while covering the landscape during periods vulnerable to soil erosion and nutrient loss. Such crops can be seeded into standing corn and soybean the end of summer to the beginning of fall, resume growth early in the spring, and harvested for grain yield in mid-June. For perennial cereal grains, the focus in Minnesota is on Kernza®, which was developed from a close relative to wheat called intermediate wheatgrass. So far, Kernza® is highly productive for the first two years after planting, and research is advancing to secure one to two more years of highly productive perenniality. Cover crops are crops planted between two cash crops to provide agro-ecological services. They are not intended to be harvested and are terminated before the next cash crop is planted. Cover crops store and cycle nutrients for the next crop, improve soil health, and impact weed, pest, and nutrient inputs.

What do winter annuals, perennial grains, and cover crops have in common? They all positively impact water quality due to their ability to uptake and immobilize residual and applied nitrogen, therefore reducing nitrate-nitrogen (NO3-N) leaching out of the active root zone of crops. Research results from the University of Minnesota show considerable reduction of NO3-N concentration in the leachate when we diversify with a third cash crop like winter annual oilseed crops, and when cover crops or perennial cereal crops are used.

Cropping systems impact water quality by changing how rainfall is partitioned between runoff, infiltration, and evaporation/transpiration. The changes to the soil surface determine, in part, how much water enters and moves through the soil. Living plant cover during the springtime allows for transpiration of water out of the soil during a season when annuals are not yet growing. A recent modeling study from Brent Dalzell and David Mulla (2018) attempted to quantify the impact of vegetation on streamflow, showing that upland management practices can impact streamflow, and, in turn, impact the in-stream sources of sediment.

Certainly, we cannot depend solely on these cropping system options to reduce nitrogen losses and streamflow, but diversification could provide a myriad of benefits not only to clean water but also to soil health, including enhanced soil structure, increased soil organic matter, improved water holding capacity, reduced runoff, and enhanced biological activity.

What makes these technologies attractive?

In Minnesota, around eight million acres of land are used to produce corn, slightly less for soybeans. One can imagine a future with a massive adoption of cover crops, as well as a widespread use of perennial cereal grains, and a third crop in the corn-soybean rotation. This may sound utopian, but these practices could be part of Minnesota's landscape in the future because we have the powerful voice of the new generations asking for a better and "greener" environment and we have our farmers who are well-informed and embracing sustainable practices for a better future.

What is the range of research underway?

The University of Minnesota is well positioned with breeding programs for the development of alternative annual and perennial crops tailored to our unique environment, as well as for the development of technological innovations like sustainable cropping systems. The social and economic dimensions of possible changes in the agricultural landscape are just emerging. An interdisciplinary team led by the Water Resources Center, and including the Center for Changing Landscapes, the Department of Agronomy and Plant Genetics, the Department of Bioproducts and Biosystems Engineering, and the Department of Computer Science and Engineering, recently received support from the National Science Foundation through its Innovations for Food, Energy and Water Systems program (NSF-INFEWS). The team is starting a study with strong social and economic components to investigate innovative approaches to supporting sustainable supplies of food, energy, and water in intensively cultivated regions. This is extremely important because mitigation measures to our water quantity and quality issues need integrated, systems-based approaches. Similarly, the Minnesota Department of Agriculture, through its Clean Water Funds, is supporting research led by the Department of Agronomy and Plant Genetics and the Department of Soil, Water, and Climate to investigate the nexus of cover crops with water and nitrogen as well as to assess an integrated landscape management for agricultural production and water quality, respectively.

Researchers from the University of Minnesota continue assessing double-cropping approaches like relay and sequence in corn and soybean production. "Relay cropping" refers to planting a second crop before harvesting the first; the growth of the first is not affected since the second grows marginally during the intercropping period, but resumes its growth rate after harvesting the first. "Sequence cropping" refers to two or more crops in succession, where the second crop is planted after the first crop is harvested. Winter camelina (Camelina sativa [L.] Crantz) and field pennycress (Thlaspi arvense L.) are excellent candidates for this technology in the temperate climate of the region. Both crops are considered bioenergy crops, overwinter, and require lower inputs than other crops. In fact, winter camelina and field pennycress have been successfully grown with double-cropped (relay and sequence) soybean; preliminary results with corn are encouraging. Double-cropping provides a temporal diversification intended to increase resources use efficiency and yield per unit of area while enhancing ecosystem services.

Robots and Big Data

Robotics is poised to become an integral part of agriculture, thereby improving the efficiency of agriculture and protecting water quality. The first large-scale adoption of self-driving vehicles occurred in agriculture over ten years ago, when farmers started buying attachments that enabled auto-steer on their sprayers, harvest combines, and other large farm machinery. Auto-steer allows large farm machinery to drive along straight paths and turn around without a human driver. Straight paths are particularly important when applying fertilizer or spraying crop protection chemicals. Auto-steer reduces overlap of adjacent passes, reducing double application of fertilizer or herbicides from one pass to another. This helps reduce contamination of water.

In the broader context, robotics are an integral part of precision agriculture. Precision agriculture is one of the major revolutions in agricultural history (Crookston, 2006). Scientists in the College of Food, Agriculture and Natural Resource Sciences (CFANS) were and still are at the forefront leading this revolution. The first Center for Precision Agriculture in the world was established at the University of Minnesota in 1995. Pioneering agricultural robotics research occurs at the University of Minnesota through collaboration between the Precision Agriculture Center and the Department of Computer Science and Engineering or the Department of Aerospace Engineering and Mechanics.

With precision agriculture, farmers can apply fertilizer or herbicides at the right rate, at the right time, at each location in a field. This precision management allows large fields to be subdivided into many small areas that each receive customized management. Each small area is termed a management zone. The benefits of precision agriculture are increased efficiency of fertilizer and pesticide use, increased profitability for the farmer, improved crop yield or quality, and reduced water quality pollution. In contrast, uniform conventional management of farms involves a single rate of fertilizer or pesticide applied across the entire field, despite a variety of soil types, landscape slopes, and crop yield potentials.

There are several examples of how robotics is applied in precision agriculture. These include managing crop stresses due to nutrients, water, weeds, insects, or disease. Crop nutrient deficiencies result when the soil is unable to supply enough nitrogen, phosphorus, or potassium to the crop, causing crop yield to suffer. Crop nutrient deficiencies can be identified using remote sensing with cameras mounted on aerial robots, commonly known as drones. Cameras on drones can be used to map crop nutrient deficiencies on a weekly schedule. These maps can be relayed to ground robots, which can travel through crop rows spreading just the amount of fertilizer needed to correct the deficiencies. This approach to managing crop nutrients provides the nutrients needed by the crop at each location in the right amount at the right time, thereby reducing excess use of fertilizer and protection water quality.

Research at the University of Minnesota on variable rate nitrogen management showed that this technique reduced annual losses of nitrates to surface water by an average of about 15 percent over many years of study.

Similarly, aerial drones with cameras can be used to identify weeds, insects, or crop diseases early enough to treat the problem with crop protection chemicals. Precision weed, insect, or disease management helps reduce the use of herbicides, insecticides, and fungicides in agriculture, thereby protecting water quality.

Precision agriculture also involves better management of irrigation water. Over irrigation leads to falling water tables and leaching of nitrates and herbicides to groundwater. Farmers can improve their pivot irrigation systems through adoption of variable rate irrigation techniques. With variable rate irrigation, farmers can vary the amount of water and nitrogen applied by each nozzle along the irrigation boom as it circles through a field.

A controller in the tractor cab is used to vary the amount of fertilizer applied across the field. Image courtesy of Aicam Laacouri.

The rate can be adjusted based on information supplied by wireless soil moisture sensor networks or by crop water stress maps obtained using cameras on drones. Crop evapotranspiration (or water use) rates often vary considerably within a field due to changes in soil depth, sand and clay content, or landscape elevation. Drones outfitted with thermal infrared cameras can detect hotter and colder areas of a field that arise due to differences in evapotranspiration. These measurements indicate which locations have crops that are experiencing water stress (hotter areas), thereby requiring more irrigation.

Precision agriculture involves collection of massive amounts of data, or big data. Data needed includes spatial and temporal variations in soil properties, landscape elevation, crop yield, crop reflectance, and precipitation for example. Processing big data is often achieved using Geographic Information Systems (GIS), geostatistics, data mining, and machine learning algorithms. Strong expertise for data mining and machine learning algorithms exists at the University of Minnesota in the College of Science and Engineering (CSE). The objectives of this processing include detecting spatial anomalies, finding unusual changes over time, data clustering and pattern recognition, identifying the causes of crop stress, and mapping areas that require customized management practices. A single field could require storage of 100 GB of data in one growing season.

Robotics is becoming an integral part of agriculture, leading to better efficiency in using crop inputs such as fertilizer and herbicides, and leading to better protection of water quality. We have come a long way from managing agricultural fields with a uniform rate of fertilizer, herbicide or irrigation water. Now, application of fertilizers, herbicides, and irrigation water can be varied across a field and with time, so that just the right rate is applied at the right location and right time using concepts from precision agriculture. The adoption of robotics in agriculture is growing rapidly, leading to new business, different types of jobs, and additional revenue in Minnesota.

At the same time, the history of agriculture in the U.S. shows that technology cannot solve all our problems without proper consideration of rural values and culture (Berry 1977). Understanding the human component is the final thread in our exploration of agriculture and water.

The People Puzzle

Nonpoint source (NPS) pollution is commonly defined as a technical, hydrological problem requiring engineering solutions. However, reducing NPS pollution also requires the action and commitment of multiple stakeholders including farmers, landowners, and urban residents. A fundamental shift in approach to water management is needed to redefine NPS pollution as a social problem. Using this lens, we begin to reimagine solutions beyond the biophysical, and delve into social causes and consequences of water resource problems. We refocus our efforts on understanding communities, developing programs that are locally relevant, building trusting relationships with farmers, and collaborating with farmers and other community members in conservation (for more, see Inspiring Action for Nonpoint Source Pollution Control).

From a social perspective, two types of actions are needed to resolve NPS pollution problems: i) individual actions such as conservation practice adoption, and ii) collective actions of multiple individuals and groups. For a long time, social scientists have examined how to motivate individual actions. Far less attention has been given to collective action, which involves understanding relationships, networks, and institutions—or what is being called social capital and social capacity.

The quality of Minnesota's waters depends on individual and community-level decisions about land use practices and policies. Farmers and other landowners are resource users and plan implementers. Individual farmers' decisions to take conservation actions can have profound impacts on the resources on which many depend. If planners and resource managers are to develop targeted conservation programs that speak to farmers' unique needs, concerns, and values, they need to understand how farmers farm, how they interact with natural resources, and how they make decisions about integrating conservation practices on their land and what motivates them to become more engaged in conservation initiatives. Further, farmer decision making does not happen in a vacuum. Their decisions are also shaped by various external factors (e.g., social networks, organizations, conservation programs, market forces). An understanding of community-level capacities is also necessary to address complex problems such as NPS pollution.

Researchers at the Center for Changing Landscapes (CCL) study how and why individuals make conservation decisions and how communities manage natural resources. CCL has collaborated with several state agencies (e.g., Pollution Control Agency, Board of Soil and Water Resources, Department of Natural Resources), counties, and watershed districts to conduct community assessments in more than a dozen Minnesota watersheds. Research findings from these projects have already informed conservation programming and civic engagement efforts across multiple watersheds. One study in particular, conducted in 2011, inspired a substantial change in Scott County's approach to conservation programming. Study results highlighted the importance of personal moral obligation and community support in motivating individual conservation actions. This spurred Scott County natural resource leaders to refocus their efforts on building better relationships with farmers and landowners to achieve water conservation goals.

University of Minnesota scholars are also conducting research to evaluate intervention strategies aimed at behavioral change. As part of the NSF-INFEWS project mentioned above, CCL will evaluate the effectiveness of benchmarking as a behavior change strategy. Benchmarking is an approach of providing social feedback about environmental conditions—for example, giving individuals information about their nitrogen management practices compared to others'—to motivate landowners to make management changes.

Interdisciplinary collaboratives that integrate social sciences with biophysical and geospatial sciences have also emerged at the University of Minnesota. For example, the New Agricultural Bioeconomy Project is a transdisciplinary research collaborative that examines the sustainability of economic, environmental, and social systems. Scientists apply participatory research processes to explore new "win-win-win" opportunities to enhance economy, environment, and community vitality in Minnesota's agricultural communities.

Protecting water resources, while maintaining or increasing agricultural productivity, requires solving the people puzzle. This means taking a people-centric approach to conservation and working side-by-side with farmers and communities to protect water resources. Improving our understanding of the social system drivers of conservation can help natural resource and policy leaders to fundamentally reshape water resource planning and programming.

The Future of Minnesota Agriculture

The health and resilience of Minnesota agriculture and water resources are interdependent. We see a future where both farmland and water resources are managed more sustainably as UMN researchers increasingly integrate the two efforts in collaboration with farmers, government agencies, and citizens.

The sample of research described in this article, along with other, equally significant work at UMN, is transforming how the landscape will look in upcoming decades. We are moving towards building soil health, instead of slowly mining it. We expect to see a more diverse set of profitable crops growing across the state and less bare soil in the springtime. We will increasingly find ways to store water and slow its movement between the time precipitation hits the ground and when the water leaves the state down the Mississippi, Red, and other rivers. In seeming contrast to the growing size of fields and field equipment, we will see farming of smaller units as management becomes customized to subfields, allowing more effective use of water, fertilizer, and other inputs. This precision agriculture is built on an innovative research and technology sector that is advancing development of sensors and decision-support systems, Big Data management, automation, and land analysis. These tools have been equally valuable for transforming the cost effectiveness of conservation activities.

Critical to all these advancements is the transformation of relationships and building capacity of communities to more effectively manage natural resources. Healthy water arises out of the dispersed involvement and networks of all types of citizens and organizations. Researchers at the University of Minnesota are becoming more sophisticated at integrating across disciplines and engaging all the varied stakeholders who are responsible for building the future of agriculture and water resource management. Together we can make a difference and conserve and preserve our valuable land and water resources for future generations.

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