MARCH 2018

The Water Underground

Implications for Agriculture and Opportunities for Change

FRESHWATER

Contents

Executive summary

Most reports that focus on agriculture and groundwater paint a bleak picture. Diminishing quantities are reported in various “bread baskets” of the world and are highlighted in this country by the epic drops in water levels in the Ogallala aquifer of the Great Plains, the Edwards aquifer of Texas and most graphically by the dozens of feet of ground subsidence in California’s San Joaquin Valley. Contamination of aquifers with nitrates and other chemicals has been foreshadowed for thirty years and is now a growing concern for the livestock or humans that must rely on this water across Europe, North America, and large parts of Minnesota.

Neither result — aquifer drawdown nor contamination — is something that rural Minnesotans want. There must be a better way forward than to tell well users that they should spend thousands of dollars on a household reverse osmosis system to provide safe drinking water; a better way than modifying irrigators’ permits after the year’s cropping decisions have been made.

We’ve been covering the topic of groundwater since the last big drought (see back cover). And we’ve been covering it for both rural and urban concerns. This report is the final in our series of three and highlights real ways to minimize the risk to our rural economy caused by groundwater shortcomings.

In this report, we identify issues facing rural groundwater users and the innovative solutions that are emerging around the state. No one can wave a magic wand and instantaneously put crops in the ground that are good for water quality and have fully developed markets that will make farms profitable again. But we can support water-friendly local products, innovative irrigators who are improving water use and reducing nutrient leaching, and farmers transitioning to new crops.

Steve Woods

EXECUTIVE DIRECTOR

Introduction: The future game

It turns out that we all want the same thing for rural Minnesota — a vibrant, long-term economy linked to world markets and a healthy place to live. This conclusion emerged during a recent think-tank on the future of Midwest agriculture[1] convened by the University of Minnesota and Professor Nick Jordan, Department of Agronomy and Plant Genetics at the University of Minnesota.

If we agree on that, the real question becomes: which of our current agricultural practices will lead to that shared vision and which will lead to another outcome?

It's not hyperbole to say that Minnesota has some of the best soil and water resources in the world. They are exported — virtually — through agricultural products that are sold around the world. Virtual water, as illustrated with a bowl of pasta, is the total amount of water used to create that meal. It may take 50 gallons of water to get that pasta to the table, compared to the half gallon we use to cook it. Every bushel of corn or pork chop takes with it some soil fertility and water reserve. As long as we keep a ledger and maintain the balance, we should be okay in the long-term. This raises the question: is someone keeping track? The answer: not very well, where groundwater is involved.

THIS REPORT is the third in Freshwater Society's *The Water Underground* series that focuses on Minnesota's groundwater future. In our first report, *Reframing the Local Groundwater Picture*, we covered groundwater conservation from the perspective of cities. In the second, *Stretching Supplies*, we added reuse and recharge of groundwater to the water toolkit that cities and the state can use. In this report we consider the sustainable use of groundwater through an agricultural lens.

The expansion of row-cropped acres and relocation of animal agriculture from drier parts of the United States to the Midwest places pressure on our groundwater resources. For example, a California dairy is exploring western Minnesota to find suitable locations that have the water to sustain a city of cows. A shrimp producer has located a hatchery and packing operations in Balaton, Luverne, and Marshall.[2]

Minnesotans want to welcome new agricultural industries and the job opportunities they bring to greater Minnesota, but in a balanced way that considers future water availability and those who rely on it. Those who need to be part of the conversation may not have a sense of what their groundwater future looks like. This lack of knowledge makes it difficult to welcome new, water-intensive agricultural industry without the nagging question of whether there will be enough water for everyone.

[1] future-iq.com/project/u-s-midwest-agriculture-scenarios-future-2016-17
[2] wctrib.com/news/4270158-southwest-minnesotas-tru-shrimp-venture-builds-regions-crops

World markets and emerging trends in consumer demand influence our agricultural economy. Exported meat alone increased 36% in the first quarter last year to become a $100 million dollar industry for Minnesota livestock producers as shown in the table below. This industry is likely to keep growing with the demand for protein in Asia.

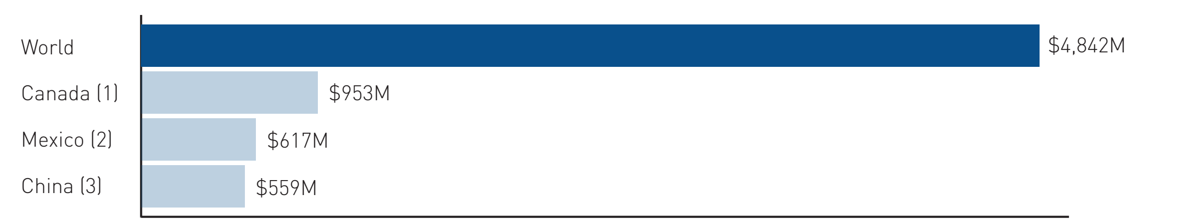
Possible extreme futures for Minnesota in response to this demand range from planting wall-to-wall corn and giving up on fishable, swimmable, drinkable water to placing extreme limits on cropping that would restore pre-settlement hydrologic conditions. Neither of these extremes is palatable. Where is the middle ground that is consistent with our shared goal of a strong rural economy and a healthy environment?

We need to acknowledge the global drivers shaping our agricultural markets while keeping decision-making here at home.

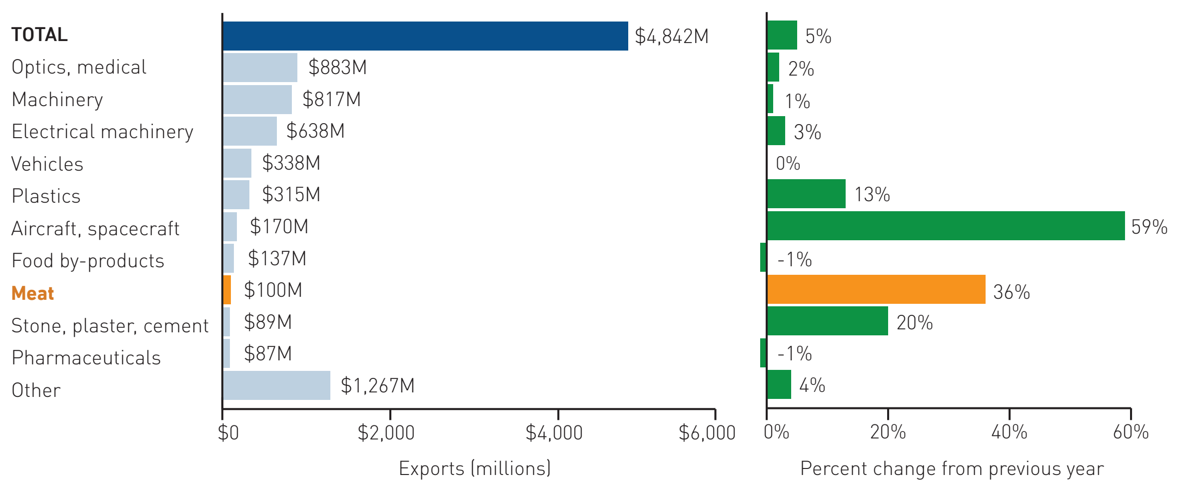
We should prevent outside forces from taking away the things that Minnesotans value, like clean and abundant groundwater. As individuals, we can make food choices that conserve and protect water and can demand clean water brands. In this report on agriculture and our shared groundwater resources we examine:

- How current and emerging practices affect groundwater quantity and quality
- Whether the status quo will allow us to achieve a robust rural economy and healthy environment.

Exports and Trends for Minnesota's Top 10 Markets, 2017-Q1



Exports and Trends for Minnesota's Top 10 Products to *World*, 2017-Q1



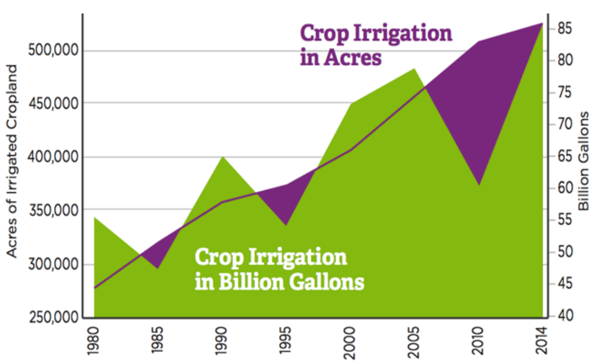
World markets and emerging trends in consumer demand influence our agricultural economy. Exported meat alone increased 36% during the first quarter last year to become a $100 million dollar industry for Minnesota livestock producers.

Source: Adaped from Minnesota Department of Employment and Economic Development (DEED)

Groundwater quantity and agriculture

SUMMARY Water scarcity is driving innovation in irrigation technology on the small percentage of Minnesota farm agreage that is irrigated. Local involvement in developing water efficiencies that protect groundwater quantity and quality can be fostered by state support for an irrigation specialist position and investment in irrigation scheduling tools delivered by Soil and Water Conservation Districts (SWCDs). Revising a state statute that prioritizes water use to reward clean-water practices, providing education on best management practices (BMPs), and funding irrigation scheduling tools and technology will increase adoption of existing approaches. On the larger percentage of farmed acres that are drained rather than irrigated, tiling redirects water and alters recharge. The long-term impact of this practice on groundwater quantity requires study.

Increasing Crop Irrigation in Minnesota



Cropland acres irrigated and total water used has been increasing since the 1980s

Source: Minnesota Environmental Quality Board 2015 Water Policy Report

Water scarcity in a desert is obvious. Minnesota is not a desert, neither above nor below ground, and yet groundwater is not always where we need it in the quantity we want.

Nothing about groundwater is obvious — where it is, how much we are using, and how use impacts surface-water features like rivers, lakes and wetlands and the ecosystems that depend on them. We turn on a pump during a dry spell and the water flows. If wetlands get a little crunchy, no worries, right?

Even in wet years, producers may need to irrigate crops grown on sandy soil after a few days of no rain. Irrigation is a way to tap into groundwater to address a short-term rain deficit. For longer duration dry spells and real drought, water resource managers and long-term groundwater supply plans come into play. Irrigators and water resource managers don't have conflicting goals. Neither group wants to deplete the water they count on. They are simply working on different time and spatial scales to manage different problems.

About a third of the wells permitted by the Minnesota Department of Natural Resources (DNR) are for irrigation, some 12,455 of the 36,636 total permits in the Minnesota Permitting and Reporting System (MPARS) database. Of the 75,542 farms in Minnesota, 2,853 farms (less than 4%) use some form of irrigation system. Or in other terms, there are 524,016 irrigated *acres* out of 19,807,839 cropland acres, which is 2.6%.[1] On the whole, the extent of irrigated agriculture in Minnesota is increasing, along with the total volume of water used.

Currently, less than three percent of Minnesota agricultural land is being irrigated.

[1] agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/Minnesota/st27_1_009_010.pdf

Photo: Carrie Jennings

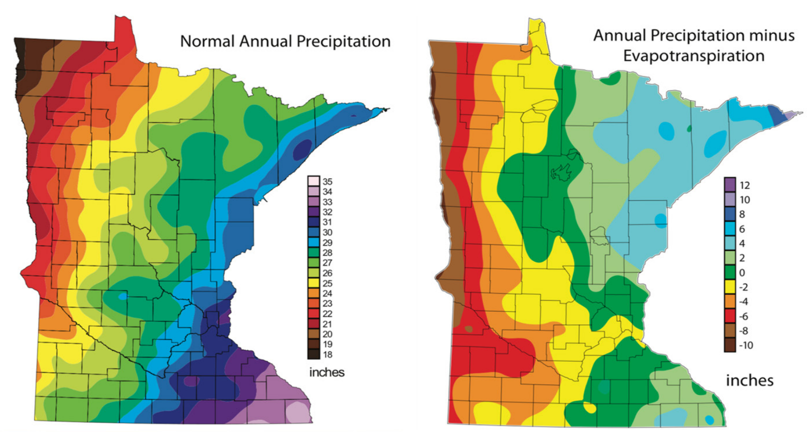
The geography of drought

Decades-long droughts that have occurred in the deep past would certainly require wholesale changes to what is grown in Minnesota. But for the run-of-the-mill dry spell, how much irrigation should be allowed in a geographic area prone to drought before neighboring wells and groundwater-dependent ecosystems are impacted?

We explore the DNR role in setting these limits later, but first must ask: what is the geography of drought in Minnesota and where does it occur most frequently? We have a strong precipitation gradient across the state; the eastern part of the state is wetter while drier regions lie to the west.

Precipitation is only part of the drought story, however. The geography of drought also depends on a soil's ability to hold water, and on patterns of evapotranspiration. That is why Minnesota's irrigated acres currently only account for 2.6% of the cropped acres.

Where are the dry spots? To answer that, let's first ask another question: what's a sandur? A sandur (plural sandar) is what it sounds like: a sandy place. It describes the broad, sandy plain that forms in front of a melting glacier. Sometimes a sandur is inundated with water and looks like a shallow lake, albeit with icebergs; other times it looks more like a braided stream. The one shown above in front of the Taku glacier in southeast Alaska is in a low-flow, braided-



Maps of Minnesota's precipitation gradient and how much of that soaks into the ground. Of the precipitation that falls, some returns to the atmosphere through evaporation and evapotranspiration by plants. The remaining moisture can enter shallow or deep groundwater.

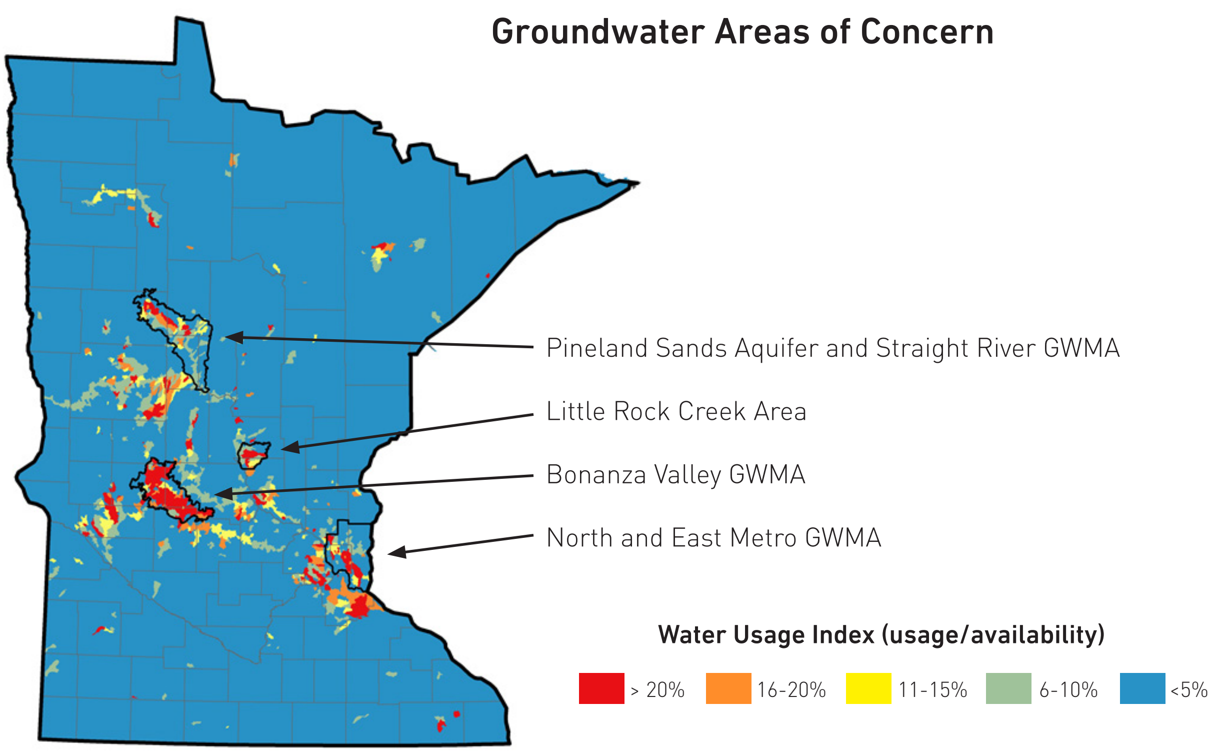
Source: University of Minnesota Extension stream phase so you can see the sandy bars and shallow channels.

Imagine planting corn there 10,000 years from now. What would you need? For starters, a lower water table to dry out the sand, fertilizer, adequate and timely moisture, and sunshine.

Scattered around Minnesota we've got great sandar that started out looking a lot like the one in Alaska, thanks to the ice sheet that used to be here. Some of the sandar span several counties: for example, the Anoka Sand Plain, Pineland Sands, and Bonanza Valley, which are well known to farmers, gravel mine operators, and geologists.

Most of our sandar got dry enough at some point in the past 10,000 years since the ice sheet retreated to have formed sand dunes. The current wet phase of our climate (on a geologic scale) has stabilized most of the dunes and made these areas prime for certain types of agriculture.

The U.S. Geological Survey (USGS) has been studying the groundwater in these sandar for almost 50 years. Some of the most extensive sand deposits in the state are partially or wholly encompassed in the Groundwater Management Areas (GWMAs) identified by the DNR.[1] These regions are where conflict over groundwater is emerging first because they are the same areas that need irrigation to be economically viable. Expect a couple more management areas to eventually be added to this list based on the distribution of sand and agriculture across the state.



The DNR has established Groundwater Management Areas [GWMA] and identified other areas of concern to address groundwater use; high-use rates can affect surface water resources or groundwater supply.

Source: Adapted from Minnesota DNR

[1] dnr.state.mn.us/gwmp/areas.html

Circles created by center pivot irrigation on sandy soil near Park Rapids, Minnesota.

Source: Google Earth

The concentration of permitted irrigation wells easily outlines the full extent of sandar in Minnesota. You could play Connect Four™ on the green circles created by center pivot irrigation on this Google Earth™ image near Park Rapids, Minnesota and essentially map the sandur.

In some parts of Minnesota, a patchwork of circles in 40-acre squares is all you'll see. In arid sandy areas crops only grow where you water them. In Minnesota, we *usually* have enough rain for less water-intensive crops to survive outside of these green circles. That *usually* represents the risk that farmers take every time they plant.

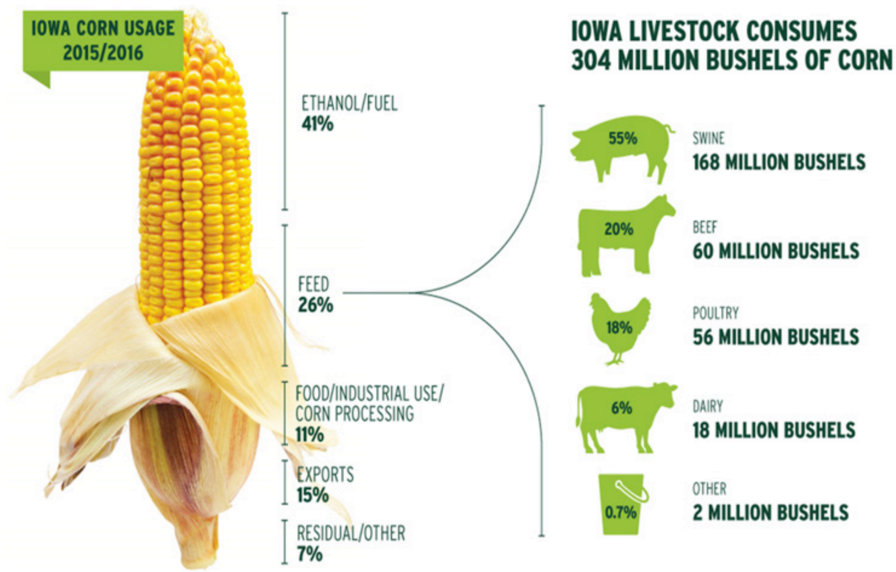
A sandur is a great substrate for crops that don't like to have damp roots or those that grow below ground (e.g. potatoes). However, because water soaks in quickly, the chemicals applied with the water can also quickly leach into the groundwater. These water-soluble chemicals get away from the crop if rates and timing are not carefully considered, which represents a financial loss to the producer and an environmental problem for everyone.

Gyles Randall, professor emeritus at the Southern Research Outreach Center at Waseca, aptly describes these cropping systems as "leaky" and field corn is among the leakiest.[1] We'll talk more about this topic in the second half of the report when we address water quality issues.

[1] mncorn.org/wp-content/uploads/2017/10/Gyles-Randall-expert-report-for-MCEA.pdf

Hierarchy of groundwater use

Two types of agricultural interests compete for sandar and other prime agricultural land in Minnesota — those growing food and those focused on commodities like ethanol. Producers who strive to make a living have their eye on the bottom line and usually grow the crops that meet market demand, no matter how they are used. For example, according to the data shown at right, Iowa corn producers are primarily focused on meeting the demand of the ethanol market.



How Iowa corn growers report their crop is used.

Source: iowacorn.org/corn-uses

If private lands are competing for shared water resources, we should consider how the water is being used when resources get scarce. Minnesota already does this by setting general priorities for the appropriation of water in Minnesota Statutes, Section 103G.26, which sets the hierarchy of groundwater use as follows:

1. Domestic water supplies and power producers with DNR-approved contingency plans
2. Water users consuming less than 10,000 gallons per day
3. Agricultural irrigation and processing of agricultural products that consume in excess of 10,000 gallons per day
4. Power production without approved contingency plans
5. Other uses that consume over 10,000 gallons per day
6. Nonessential uses of water

These priorities are not very detailed. Priority number three lumps all aspects of the very large agricultural sector into one category. It could be further refined to emphasize critical agriculture (food production) over commodity crops. Or it could prioritize crops that cause less environmental impact or producers that introduce water efficiencies.

We might want to do this to incentivize practices that benefit all of us. Minnesotans bear additional costs when certain crops are grown, because of pollution or increased demand for water. This approach may seem heavy-handed but it does not mandate behavior change. Rather, it allows those who use and share the resource to come up with solutions.

In the metropolitan area, cities that share groundwater resources also share data to plan for the future of their common aquifer. Now is the time to better equip rural communities to collaborate on groundwater planning. Planning exercises should involve all of the big water users — domestic, agricultural, and industrial.

Some communities in western Minnesota have been forced to coordinate because so little water is available or is of poor quality. They have banded together to form rural water associations. Communities like Dawson are being eyed by rural water systems because they have groundwater that others need.

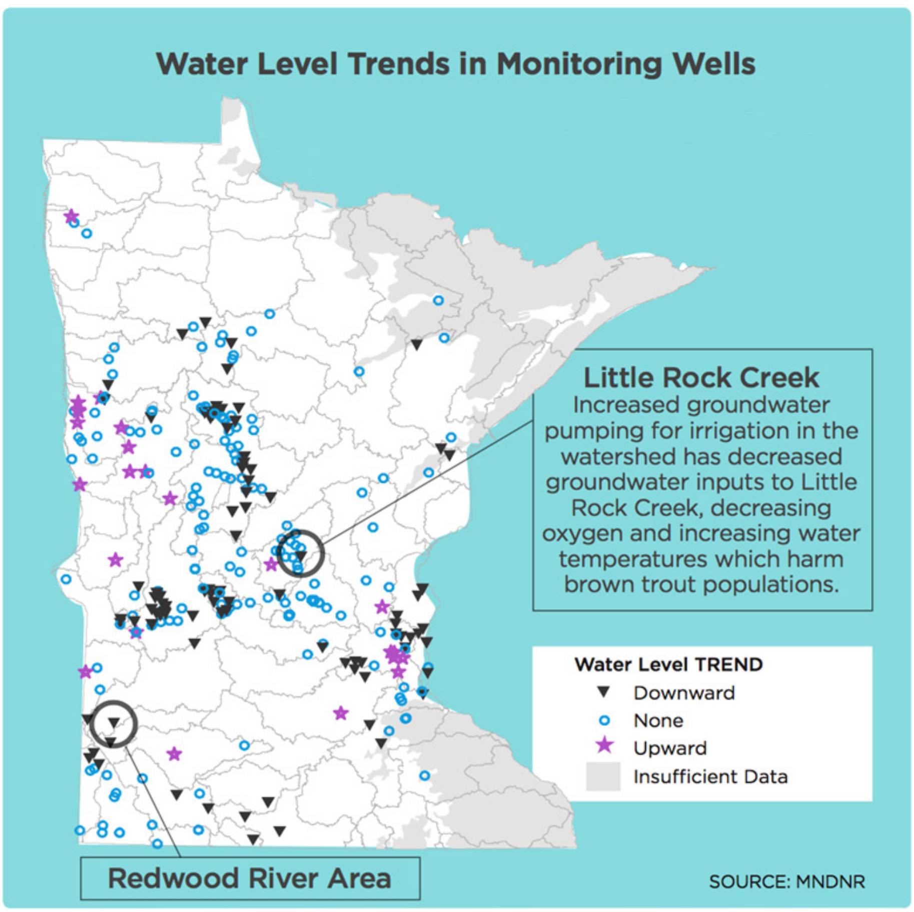
Some big water users who would like to move in or expand and don't want to risk developing a site without a guaranteed water supply conduct their own aquifer tests. Such aquifer tests are not a requirement of the state in most cases.

Information on how many wells or rural communities share an aquifer and the stability of the water levels is available but unfortunately this information is not readily accessible. The picture is fuzzy and there are no projections of future demand.

Compiling the data currently requires considerable effort and some experience, or at least persistence, because the data are acquired, interpreted, and archived by multiple agencies with different functions and goals. The Minnesota Department of Health (MDH) provides access to well logs that show which wells draw from which aquifers. The DNR and Minnesota Geological Survey (MGS) interpret the well drillers' logs and project the extent of the geologic units hosting the water. The DNR has an observation well network that records water levels. Unfortunately, although there are a lot of readings from around the state, they are rarely compiled or interpreted in a way that illuminates long-term trends.

State and federal agencies that have been collecting and keeping these data are beginning to compile them to make them available. This effort was initiated by MDH. DNR will be the keeper of the database.

We encourage this effort to compile, interpret, and provide accessible information. It is essential for groundwater-dependent parts of the state to have in order to plan for the future.



While not all of Minnesota has water supply issues, numerous wells have shown a decrease in water level in recent years (1993-2012)

Source: Minnesota Environmental Quality Board 2017 Environment and Energy Report Card

Irrigated potato test plots near Becker, Minn.
Photo: Brian Bohman

Permission to irrigate

Keeping track of well permits, dealing with well-interference issues, and developing safe-yield estimates is the purview of the DNR, according to statute and rule. Though this does not necessarily make them well loved, it is necessary to protect ecosystems.

Fortunately, the DNR has recently been stepping into this role. The recent ruling on White Bear Lake[1] went against the DNR when the judge in the case ruled in favor of the neighbors who maintained that the DNR was allowing so much water to be drawn from the ground that it impacted lake levels. However, by losing, the DNR actually won the ability to more fully exercise authority granted to them. Going forward, they could use the ruling to take a harder look at permits, do more aquifer tests and make sure new wells around the state don't impact surface water bodies.

When to irrigate

Timely rain is a precious gift to a farmer during the growing season and 2017 was about perfect. When rain doesn't fall gently at an inch or two a week, irrigation may be required to optimize yield. How do those who irrigate decide when to water? Do they water on a regular schedule regardless of when it rains, because their neighbor does, or as added insurance because they don't know when it will rain next?

As weather and rainfall patterns in Minnesota become harder to predict, the future of agriculture depends in part on improved efficiencies. For irrigated agriculture, this means improving on-farm water management. Upgrades in irrigation-system technology can enhance water-use efficiency, with the co-benefits of lower electric bills, less leaching, and higher profits for the farmer.

An irrigation specialist who works with producers and crop consultants was identified as a critical need by the irrigation community and agricultural stakeholders. A specialist could give direct support to irrigators on scheduling and soil-water monitoring designed to increase water-use efficiency and thereby also reduce nitrogen losses. The position with University of Minnesota Extension was established but not fully funded and has proven difficult to fill. To attract and retain a qualified candidate, it needs to be a full-time, tenured position with stable funding.

[1] fmr.org/news/2017/09/08/whitebearlake-ruling

Smarter irrigation

Irrigation scheduling — the automating of crop watering using data on rainfall, soils, and plant maturity (stage) — has been evolving since the 1970s in Minnesota. Its adoption is being coordinated in certain geographic areas — you guessed it, the sandar — to not only address water management at the farm level, but also at the watershed level, to proactively deal with competition between users' demands and environmental impacts.

In the past, irrigation scheduling was based on: simplified estimates of water inputs (irrigation and precipitation); an water stored in soil based on its holding capacity; and water out, based on crop use. This method, known as the "checkbook", has long been promoted by extension services from land grant universities in the upper Midwest, including the University of Minnesota. Growers could use values from tables provided to them by the university. This approach has since been adapted to the digital age; farmers now use these estimates in a spreadsheet-based form.

This method of tracking soil water balance still depends on the regular measurements of soil moisture and is inaccurate if used without them. A recent study by the University of Minnesota has also found that the checkbook method may result in over-irrigation by as much as 50% if weekly measurements of soil moisture content are not incorporated.[1] Over-irrigation can cause nutrients to leach from the rooting zone into the groundwater where they are pollutants.

New irrigation scheduling methods being developed are more accurate than the checkbook method and reduce loss of nutrients to the environment. For example, irrigation scheduling software automatically updates when precipitation is received; accounts for crop use, which is dependent on maturity; and incorporates data from soil moisture sensors.

Parallel to developments in banking that are moving us from paper checks to electronic payments, irrigation scheduling is moving the irrigator into the automated world of an iPhone app for irrigation scheduling. Currently, 25% of irrigators in Minnesota use the checkbook and 10% use soil moisture measurements to schedule irrigation. Qualitatively assessing crop condition and soil feel are far more common methods to schedule irrigation (USDA NASS Survey 2013).[2]

With the perfect combination of sandy farmland and recreational lakes, Otter Tail County became an early adopter of irrigation-scheduling technology. It expanded exponentially after 2005 with the arrival of a new district manager at East Otter Tail SWCD. Lake levels are currently high so scheduling is being used primarily to reduce leaching of nitrogen fertilizer rather than manage groundwater levels. Near Little Rock Creek in Benton County, a pilot irrigation scheduling project is being used in response to well interference with a cold water stream. The Benton SWCD manager in Foley is leading the effort.

The scheduling tool described here is not yet available for everyone; in fact it is currently available in only one watershed and is being developed for another one. The rollout for the rest of the irrigated areas in Minnesota is taking more time than expected. Current funding levels do not provide adequate time to develop the software or training and outreach SWCDs need.

IoT (Internet of Things) in the field

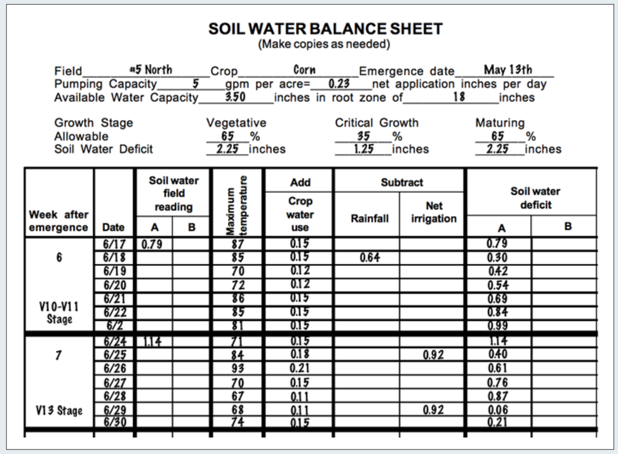
Leaky faucets, no matter where they are, waste water. In a farm operation, the equivalent of a running toilet is a bad irrigator nozzle. You may have driven by one that was acting up or shooting off in an odd direction to water the county highway.

Uneven water application in a field also results in less-than-optimal moisture distribution. By automatically logging how much water is being delivered, data loggers can improve reporting, identify faulty nozzles, and optimize rates of water application. Advances in cellular and IOT technology have made these devices accessible and affordable options for Minnesota irrigators.

[1] wrs.umn.edu/seminar-88
[2] agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey

Irrigation scheduling methods

In the past, irrigation scheduling was calculated on paper, and by hand. This technology has since been adapted to the digital age; farmers can now access these estimates in a spreadsheet-based form, or on smart phones and computers.



SOIL WATER BALANCE SHEET
(Make copies as needed)

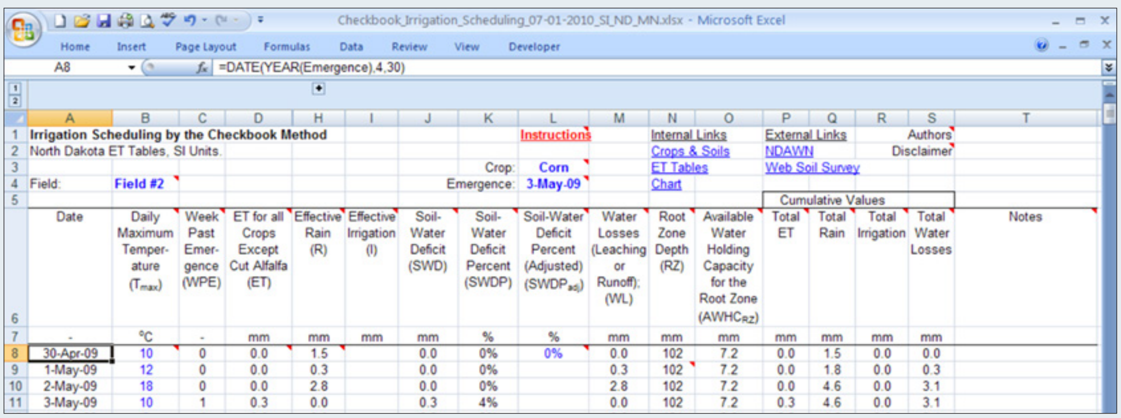
Field #5 North Crop Corn Emergence date May 13th
Pumping Capacity 5 gpm per acre= 0.23 net application inches per day
Available Water Capacity 3.50 inches in root zone of 18 inches

Growth Stage	Vegetative	Critical Growth	Maturing
Allowable	65 %	35 %	65 %
Soil Water Deficit	2.25 inches	1.25 inches	2.25 inches

Week after emergence	Date	Soil water field reading A	Soil water field reading B	Maximum temperature	Add: Crop water use	Subtract: Rainfall	Subtract: Net irrigation	Soil water deficit A	Soil water deficit B
6	6/17	0.79		87	0.15			0.79	
	6/18			85	0.15	0.64		0.30	
	6/19			70	0.12			0.42	
	6/20			72	0.12			0.54	
V10-V11 Stage	6/21			86	0.15			0.69	
	6/22			85	0.15			0.84	
	6/2			81	0.15			0.99	
7	6/24	1.14		71	0.15			1.14	
	6/25			84	0.18		0.92	0.40	
	6/26			93	0.21			0.61	
	6/27			70	0.15			0.76	
	6/28			67	0.11			0.87	
V13 Stage	6/29			68	0.11		0.92	0.06	
	6/30			74	0.15			0.21	

The "checkbook" method (at right) relies on data provided daily by University of Minnesota Extension, using a worksheet. Source: Adaped from UMN Extension

Farmers can now do the same thing in a digital spreadsheet format (below). Source: NDSU Extension

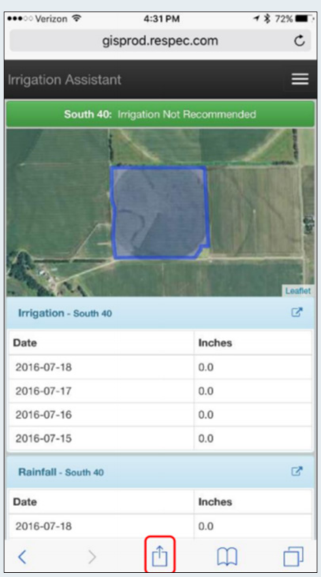


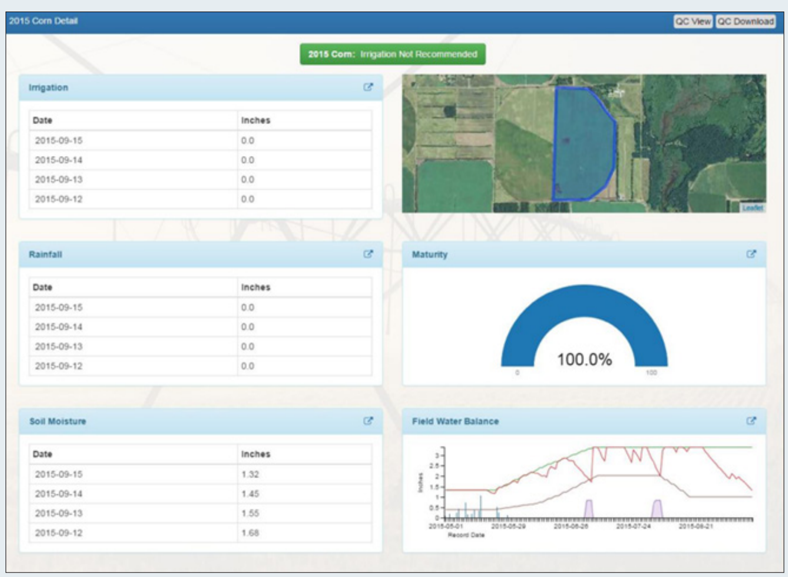
Checkbook_Irrigation_Scheduling_07-01-2010_SI_ND_MN.xlsx - Microsoft Excel

Home Insert Page Layout Formulas Data Review View Developer

A8 =DATE(YEAR(Emergence),4,30)

	A	B	C	D	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Irrigation Scheduling by the Checkbook Method								Instructions		Internal Links		External Links			Authors	
2	North Dakota ET Tables, SI Units.										Crops & Soils		NDAWN			Disclaimer	
3								Crop:	Corn		ET Tables		Web Soil Survey				
4	Field:	Field #2						Emergence:	3-May-09		Chart						
5													Cumulative Values				
6	Date	Daily Maximum Temper-ature (T_{max})	Week Past Emer-gence (WPE)	ET for all Crops Except Cut Alfalfa (ET)	Effective Rain (R)	Effective Irrigation (I)	Soil-Water Deficit (SWD)	Soil-Water Deficit Percent (SWDP)	Soil-Water Deficit Percent (Adjusted) ($SWDP_{adj}$)	Water Losses (Leaching or Runoff); (WL)	Root Zone Depth (RZ)	Available Water Holding Capacity for the Root Zone ($AWHC_{RZ}$)	Total ET	Total Rain	Total Irrigation	Total Water Losses	Notes
7	-	°C	-	mm	mm	mm	mm	%	%	mm	mm	mm	mm	mm	mm	mm	
8	30-Apr-09	10	0	0.0	1.5		0.0	0%	0%	0.0	102	7.2	0.0	1.5	0.0	0.0	
9	1-May-09	12	0	0.0	0.3		0.0	0%		0.3	102	7.2	0.0	1.8	0.0	0.3	
10	2-May-09	18	0	0.0	2.8		0.0	0%		2.8	102	7.2	0.0	4.6	0.0	3.1	
11	3-May-09	10	1	0.3	0.0		0.3	4%		0.0	102	7.2	0.3	4.6	0.0	3.1	





Irrigation scheduling tools are also available on smartphones and computers in limited areas.
Source: Benton County SWCD and RESPEC

Weather stations to measure rainfall, sunshine, humidity, wind, and temperature are key parts of this new IOT infrastructure. SWCDs and the MDA have invested in the Ag Weather Network to create the backbone of an irrigation scheduling network. Farmers are also installing weather stations to monitor key variables in their own fields.

Beyond simply measuring the weather, farmers can easily measure the amount of water in the soil, which is the most important factor in managing irrigation efficiently. Farmers have access to a variety of tools that are being adopted on more and more farms. They can also use old-school and low-cost soil samples to measure soil moisture.

New irrigation infrastructure is also becoming available to farmers. Known as "variable rate irrigation", this technology lets growers apply the right amount of water to the right areas of the field, reducing overwatering and underwatering. Using maps of their soil, farmers can irrigate most efficiently while protecting the environment

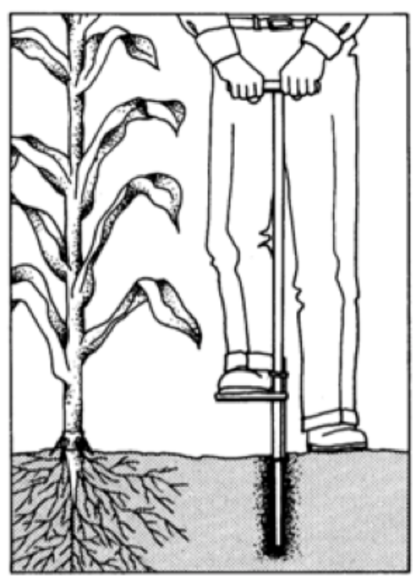

Photo: East Otter Tail SWCD

The Internet of things (IoT) is the network of physical devices, vehicles, and other items embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data. The IoT allows objects to be sensed or controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, resulting in improved efficiency, accuracy, and economic benefit with reduced human intervention. When IoT is augmented with sensors and actuators, the technology becomes an instance of the more general class of cyber-physical systems, which also encompasses technologies such as smart grids, virtual power plants, smart homes, intelligent transportation, and smart cities.

Source: Wikipedia

Various methods to measure soil moisture content include portable soil moisture sensors [Spectrum Fieldscout™ TDR 300], semi-permanent Watermark sensors [Irrometer], and traditional soil sampling.

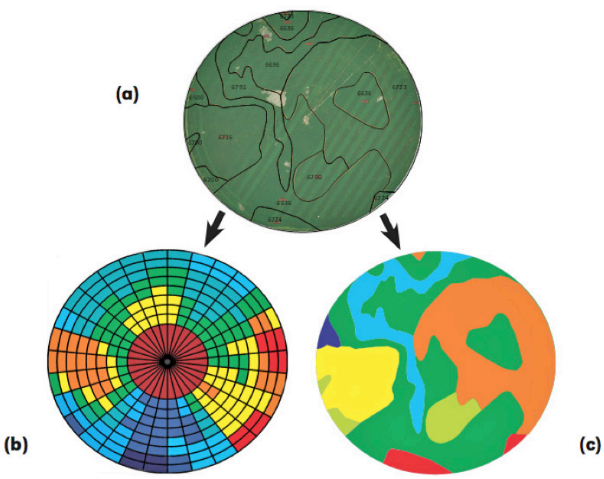
Source: UW Extension and NDSU Extension



and their crops. This technology has not yet reached anywhere close to its full potential. Out of 175,000 center pivots and linear irrigation systems across the U.S., it is estimated that only 200 have this technology and only 50 are using the technology to its full potential.[1]

Despite the promise of this technique, Minnesota is behind the curve when it comes to variable-rate irrigation research and the future doesn't look promising. The Sand Plains Research Farm in Becker, Minnesota, the primary location for irrigation research conducted by the University of Minnesota, is being relocated because the owner decided to develop the land.[2] As a result, major investments in infrastructure will be required within the next one to two years to develop a new research station in another location. Delaying this would hinder development of new strategies to protect groundwater in Minnesota, while investing in the station could put Minnesota at the forefront of deploying this technology and getting it into the hands of irrigators.

Imagine again, the green circles of irrigation near Park Rapids (see page 6). What if each of those center pivot irrigators were connected to a scheduler, and all of those schedulers communicated the condition of the soil as well as the aquifer in the well field? If water levels in part of the aquifer started to drop too quickly, the smart well field could make adjustments before any adverse response was seen in other wells, streams, wetlands, and lakes. Irrigators would have avoided a problem and intervention by the DNR would be unnecessary.



Quarter section of land showing soil mapping units (a), 270 potential center pivot control zones (b), and the potential map for a system equipped with individual sprinkler controls and seven management zones (c).

All fields have variable soil conditions, and new variable-rate irrigation sprinkler technology can account for that variability to apply water at different rates to different areas of the fields, resulting in a more efficient use of water.

Source: University of Nebraska-Lincoln Extension

CASE STUDY:
San Luis Valley, CO – Cooperation

The San Luis Valley in South Central Colorado is a flat plain with mountain ranges to the east and west. It is arid, receiving seven inches of rain a year, less than Phoenix, Arizona.

Large-scale potato, lettuce, quinoa, hay, and barley production is supported by irrigation.

Irrigation wells have tapped once-vast groundwater reserves. Heavy pumping has depleted aquifers by more than one million acre-feet, enough groundwater to supply 4-5 million households for a year. State regulators were considering shutting off scores of wells which would have devastated the economy.

Instead, irrigators retained local control and created a local irrigation market. They charge themselves to pump groundwater and use the revenue to pay others to fallow their land. Tens of thousands of acres have come out of production, but the plan has allowed the local economy to stay afloat. An irrigator who invests in planting a crop has sufficient water to realize a return, even in a dry year, and they in turn are helping those who are not producing a crop that year.

[1] doi.org/10.1007/s00271-012-0365-x
[2] startribune.com/xcel-s-plan-for-becker-plants-is-uprooting-university-of-minnesota-research-farm/420791963/

Soak it in

Other, more efficient ways to irrigate are being explored for row crops such as irrigation guns and low-pressure emitters that direct water downward. The Irrigators Association of Minnesota shares resources and tools through its newsletter and at sponsored events, promoting solutions to irrigation problems that avoid regulation. This means that they encourage their members to step up and make voluntary improvements to their systems.

We know drip irrigation minimizes evaporation and directs water and nutrients directly to the crop roots. This method is typically used by fruit and horticultural growers with planting that doesn't happen every year. Some farmers, such as the one featured in the article on the next page, are trying to figure out how to use it for annual row crops, to save their crops and money.

Too wet to plow

To address a dry spell, we have many options that have not yet been fully implemented. The opposite problem is also an issue; plenty of fields in Minnesota are too wet to plow when it is time to plant, too soggy in the fall for harvest, or both. Some may even have drought and wet conditions in the same year.

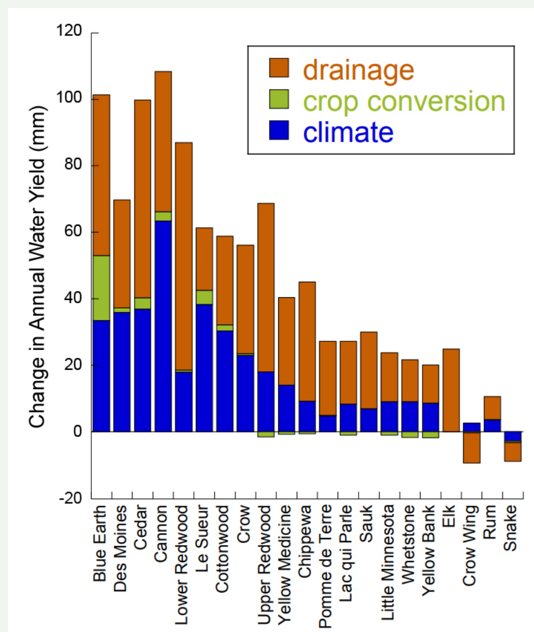
Since Europeans arrived in Minnesota we've encouraged and incentivized property owners to drain "problem" fields. Drainage was even funded by the state in order to encourage settlement. It has been an abrupt turnaround in some producers' eyes but the adverse consequences of drainage began to be raised in the 1960s.

Getting back to the shared fear of aquifer depletion, the practice of redirecting natural recharge through tile and ditches to flow out of the state needs examination. We are starting to learn that in both urban and rural areas, slowing water down and allowing it to soak in before it reaches the rivers and lakes is beneficial. It minimizes downstream flood impacts and allows water to return to, or recharge the aquifer.

Agri-karst or the invisible world of patterned tile

Sinkholes *do* appear in farm fields in southeastern Minnesota. Tractors, manure lagoons, and even buildings are swallowed up. Streams sink mysteriously into the ground, reappearing miles away in some cases. But "agri-karst", a term coined by University of Minnesota geologist Dr. Calvin Alexander refers to the much more pervasive and seemingly less ominous tile network that lies hidden beneath many fields. In trying to understand the effect that tile drainage had on a landscape and its

Impacts of Drainage



"Seasonal and annual water yield (flow) and runoff ratio were found to increase by >50% since 1940 in half of the watersheds, with no statistical change in the others. .... climate and crop conversion could explain less than half of the observed increase in river flow .... Artificial drainage was identified as the largest driver of increased flow.... The increase in flow is not inconsequential and was shown to be correlated to widening of the river channels over the past 70 years."[1]

Change in water yield from watersheds resulting from drainage, conversion to crops, and climate.

[1] doi.org/10.1002/hyp.9738

Going underground in corn country: Western Minn. farmer tests economics of subsurface irrigation

By Tom Cherveny, Aug 1, 2017 | West Central Tribune

HANLEY FALLS — Irrigation can make economic sense for many corn farmers in Minnesota, but it is not known if a more costly investment in subsurface irrigation can produce the yields to justify the extra cost.

Brian Velde aims to find out, thanks to an Innovation Grant from the Minnesota Corn Growers and the help of a University of Minnesota researcher.

Velde, who farms along the Yellow Medicine River about six miles south of Granite Falls, installed a subsurface, drip irrigation system on 58 acres of corn land. The soil varies greatly across the acreage, with areas of light, sandy soils and other areas with heavier, rich soils.

"A lot of variability. There wasn't a good answer for yield responses," Velde said. Using the latest technology, for more than a decade, he precisely adjusted fertilizer and seeding rates according to the soil types.

All the same, there were years when he would watch the corn on the sandy soil burn up and produce nothing while just 1,000 feet away he could harvest 250 bushels per acre on the heavy ground.

He started researching his irrigation options a few years ago, and then learned about a Kansas company's subsurface system.

Last year, Nutradrip installed its pressurized drip tape by plowing it into the ground. It runs in parallel lines 5 feet apart, with small drip emitters buried about 14 inches deep. It's placed so that every corn plant is within 15 inches of a drip emitter.

A 10-horsepower pump pulls water from the Yellow Medicine River, runs it through three sand filters and delivers it through a trenched, 8-inch pipe to the drip tape.

Velde operates it all from a computer. It enables him to both water and fertilize the corn. He feels the ability to fertigate may prove to be the biggest benefit of the system. It allows him to spoon-feed the corn just the amount of nitrogen needed and when it's most needed: that mainly being the month of July.

It has allowed him to reduce the amount of nitrogen that is land applied. And, the system's efficiency means there should be no nitrogen leaching into the groundwater.

This July has been a relatively dry one on the farm, which only underscores for him the value of being able to irrigate. The system allows him to control the drip rate so he is able to provide more water to the corn in the light soils as compared to the corn in the heavier soils.

There is no loss to evaporation as occurs with overhead irrigation systems, he said. He also pointed out that by virtue of not spraying the canopy and soil from above, he has no worries about disease or flushes of weeds.

There's also another benefit of this subsurface system. He is able to pump water and cool the soil when soil temperatures exceed 82 degrees and stress the corn. A series of temperature monitors spread across the field warn when temperatures are reaching stress levels.

There is a lot of data on the benefits of this technology in southern corn-growing states like Kansas and Nebraska, Velde said. But what about Minnesota, where there are fewer days of heat stress?

He has reason for optimism. July has been dry enough on his farm that absent the irrigation, he's convinced his corn on sandy soil would be a bust this year. With the irrigation, he's looking at lush rows of corn with double ears.

More than half the irrigated acres in the state of Minnesota were planted to corn in 2015, the latest year crop-specific figures are available from the state Department of Natural Resources. There were 616,100 acres reported irrigated that year, and 318,200 of those were for corn.

Test strips that run through the field will allow Velde and Dr. Jeff Strock, researcher with the University of Minnesota, to statistically quantify the corn yields on the different soil types with and without irrigation. Velde pointed out that it is not just the increased yields that can matter, but when they occur. A bigger yield during a dry year could mean the benefit of a higher per bushel price on the market, he explained.

His irrigation permit allows him to pump the equivalent of about 6 inches of water, or 9.6 million gallons of water in a season. In a drought event, the right to irrigate can be suspended.

The Corn Growers' Innovation Grant allows for three years of research at the site. Velde noted that it may take more years than that to fully know the economics of the investment.

waterways he concluded that the black plastic perforated tubes acted much like caverns and conduits in rock allowing the free and quick passage of water. They hijack the drainage system. In fact, they *are* the drainage system.

Tiling is an old practice. The Wikipedia page on agricultural tile drainage refers to Cato the Elder, born in about 234 B.C. and Pliny the Elder, who lived about 250 years later when discussing its origin. Midwesterners, as is our custom, have gotten a lot more efficient about tiling. Instead of using ceramic tile sections dug by hand into a field, we now load a coil of flexible tubing into a chain-saw-like trenching tool that unspools, places, and covers the tubing in one pass (see photo below right). Tile drainage is one of the biggest infrastructure project since the interstate highway system and is completely invisible to most people. And unlike the highway system, the tiling network has been privately financed.

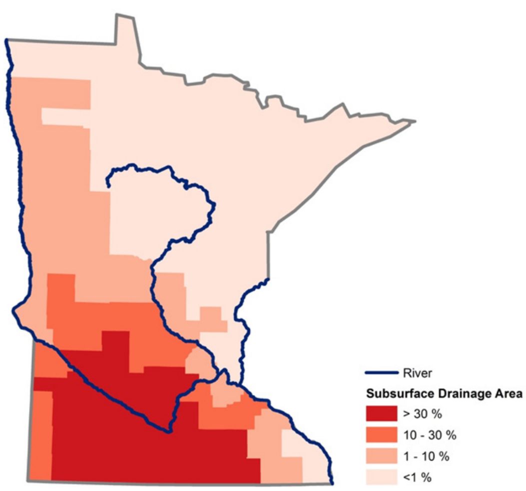
Although there are clearly benefits to the producer to tile, such as increased yield, reduced field erosion, and the ability to get into the fields earlier in the season, the consequences are a growing public burden. They affect everyone downstream by increasing the flow in rivers in extensively tiled watersheds, widening them, eroding farms and towns, and carrying more sediment and nutrients to downstream reaches of the Minnesota and Mississippi rivers, Lake Pepin, and ultimately the Gulf of Mexico.[1]

The effect on groundwater? We are still learning how to quantify the impact. However, with all that exported water, it makes sense that our long-term aquifer storage is decreasing. We just haven't found a way to adequately measure that impact yet.[2]

Tile drainage reduces surface storage of water, changes the pattern of evapotranspiration, and shifts water to streams at certain times of year, not allowing it to soak into the ground. These changes to water balance are profound and have altered our hydrology in ways we are still trying to understand.

[1] freshwater.org/wp-content/uploads/2017/01/ChangeInMinnRiverReport_8.5x11.pdf
[2] Drain Tiles and Groundwater Resources: Understanding the relations, Minnesota Ground Water Association white paper, November 2017

Tile drainage in Minnesota



Tile drainage in Minnesota is currently concentrated in the Minnesota River watershed but is expanding across the state to all soil types.

Sources: Graphic above adapted from USDA-NASS (2012); photo at right NDSU Extension

Recommendations for water quantity

Concentrated areas of high-capacity irrigation systems impact groundwater levels and jeopardize long-term groundwater use. Drought-prone areas need planning to ensure equitable use of shared groundwater. Tiling has an unquantified impact on groundwater recharge that needs to be understood.

We recommend more of these emerging practices in irrigation:

Minnesota Department of Natural Resources

- Use supplemental permit conditions to phase in aquifer-monitoring technology in heavily irrigated areas of the state that are not addressing their challenge through local collaboration
- Encourage the use of data loggers for reporting water or electriciy use and irrigation optimization
- Examine water appropriation permits and perform aquifer tests to determine impact

University of Minnesota Extension and Minnesota Department of Agriculture

- Develop educational programs for producers and SWCD staff related to irrigation scheduling, soil-moisture monitoring, and variable-rate irrigation
- Update recommended irrigation management practices based on recent research
- Invest in infrastructure for variable-rate irrigation research and demonstration project at the Sand Plains Research Farm

Local governments involved in rural water supplies including Soil and Water Conservation Districts

- Apply for Clean Water Funding to expand irrigation scheduling software to more areas
- Develop cost-sharing to help irrigators implement BMPs and upgrade equipment
- Remove marginal, sandy lands from production by purchase and voluntary easement enrollment

Producers

- Invest in smart irrigation technology such as variable rate irrigation
- Incorporate soil moisture measurements into irrigation scheduling
- Adopt new smart irrigation scheduling applications in locations where currently available

We recommend more coordination in managing shared groundwater:

Minnesota Department of Agriculture with Department of Natural Resources

- Use existing data layers to identify areas where the majority of recharge is occurring
- Quantify how much recharge is being intercepted by patterned tile
- Increase training of local governments to work with irrigators

Minnesota Department of Natural Resources

- Equip rural communities to share groundwater data by providing available trend information on aquifer levels to water-appropriation permittees each year
- Create safe-yield estimates for aquifers, beginning with those that may result in adverse agricultural impacts
- Support efforts with adequate permit fees
- Continue to streamline simple permits while quantitatively evaluating those in stressed areas

Legislature

- Pass study bill to examine recharge in groundwater-stressed parts of the state through easements on: wellhead protection, drinking-water-source management, and geologically appropriate areas
- Refine prioritization of water usage in Minnesota Statute 103G.26 to acknowledge that some agricultural practices result in additional costs to the state
- Authorize long-term funding (i.e. tenured position) for an irrigation specialist
- Appropriate money to redevelop the University of Minnesota Sand Plains Research Farm

Groundwater quality and agriculture

SUMMARY Leaching of nitrogen fertilizer from agricultural areas is increasing drinking-water treatment costs for all Minnesotans. The state agencies with roles in water protection only respond after an impact occurs; no agency prevents the pollution of clean groundwater, like that in the area of the state that is being converted from forest to crops. Despite widespread best management practice (BMP) adoption, nitrate levels in groundwater are not decreasing. With nitrogen comes pesticides. Meaningful reductions in groundwater contamination will require a shift in cropping systems.

Stopping the nitrogen leak

Nitrogen is a critical input for agricultural productivity but too much of a good thing can be bad. This potent water pollutant is very difficult to contain once it has been introduced into the environment. Nitrogen fertilizers require significant private investment and no one wants to lose those dollars. Yet by some estimates, around 40% of applied nitrogen is not taken up by crops.

Phosphorus, another nutrient that is applied and lost to waters, is more of a problem for surface water than groundwater so will not be further discussed in this report.

Nitrogen can escape from farm fields and enter shallow groundwater. Intensively monitored fields in the Root River watershed lose from 10 to 34 lbs of nitrogen per acre as measured at the field edge. Research at the University of Minnesota Southwest Research and Outreach Center has shown similar results where tile drained corn and soybean cropping systems lost on average 50 lbs of nitrogen per acre annually.[1]

When it comes to deeper groundwater, areas with sandy soils are even leakier. Research by the University of Minnesota shows that nitrate leaching on sandy soils can range as high as 60 and 160 lbs of nitrogen per acre for corn and potato production, respectively.[2] A study in the Wisconsin Central Sands found nitrate leaching was 105 and 180 lbs of nitrogen per acre for sweet corn and potato cropping systems respectively.[3] These loads are very high because the system is fundamentally leaky.

The research on the major sources of nitrate in agricultural systems is largely settled and MDA has conducted a literature review on the subject.[4] The strategy used to reduce these known nitrogen leaks in agriculture has relied on a set of BMPs collectively known as the 4Rs — applying nitrogen fertilizer at the right time, in the right place, at the right rate, and with the right source. These strategies have been developed by the University of Minnesota and supported by the Minnesota Department of Agriculture (MDA).

So far, these practices have played an important role in reducing the impact of agriculture on groundwater and many producers are working hard across the state to implement these BMPs. In the irrigated areas of the state, which are the most vulnerable, the MDA found in a 2012 survey that 71% of farms producing corn are applying nitrogen fertilizer at or even below the recommended rate.[5] Other new and promising strategies such as using slow-release fertilizers, nitrification inhibitors, and variable-rate fertilizer applications are also becoming more commonly adopted.

[1] doi.org/10.2134/jeq2001.302337x
[2] doi.org/10.2134/agronj1998.00021962009000010003x, doi.org/10.2134/jeq1996.00472425002500050008x
[3] doi.org/10.2134/jeq2001.3041176x
[4] mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan/fertsourcenitrategw.aspx
[5] mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/nutrientmgmtsurvey.aspx

However, despite the adoption of BMPs by producers, we have not yet seen a broad reversal in the increasing trend of nitrate concentration in groundwater. This disconnect between effort and outcomes can be explained by two factors. First, there is a lag time of decades between when nitrogen fertilizer is lost from the root zone and when it is detected in monitoring wells or water supply wells. It might take decades or longer for today's changes to have an observable effect. Second, even with the full implementation of the 4R management strategies currently available, our current cropping system is simply too leaky to keep groundwater clean.

An 80% adoption of right rate and right timing 4R BMPs across the central sands of Minnesota would decrease nitrate load to surface water and groundwater by only 8-12% according to a tool developed by the University of Minnesota to estimate losses under different management practices.[1] These decreases will not be enough to shift the balance away from continued degradation of groundwater.

Clean groundwater will in part require a shift in the cropping systems on vulnerable soils in addition to the adoption of BMPs by farmers that has largely already occurred. This shift will mean 1) fewer acres of nitrogen-intensive crops and more acres of perennial vegetation that do not require high nutrient inputs; 2) cover crops before and after the nitrogen-intensive crop is mature to scavenge excess nitrogen from the soil; 3) a longer rotation between nitrogen-intensive crops and those that do not require inputs. In other words, we need to put more clean water into the ground to dilute the nitrogen pollution that is already there and continues to occur as a result of our leaky cropping systems. In the Wisconsin study previously referenced, each acre of irrigated vegetable production would need to be offset by five to seven times as much land supplying water free of nitrate to keep groundwater below the health risk limit for nitrate.

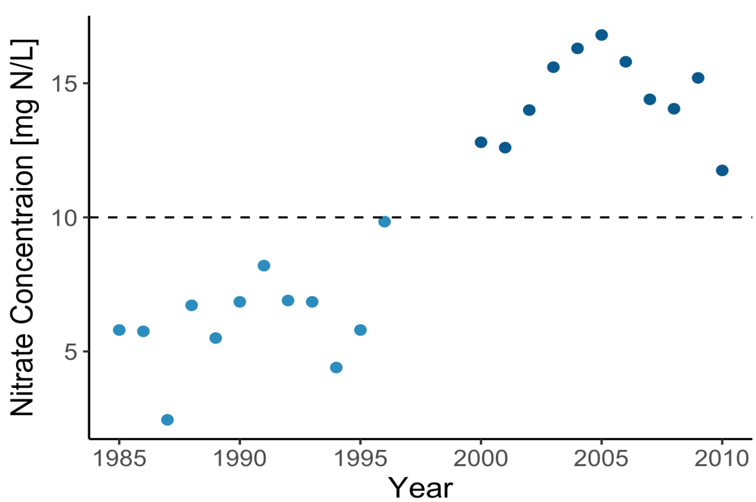
Location, location, location

Since significant state investment is required to address the environmental degradation from excess nitrogen in groundwater, we simply can't afford to continue with the status quo. Bedrock aquifers such as those supplying the drinking water for towns and private well owners in the southeastern portion of the state are vulnerable to pollution, largely because the rock layers are close to the surface and have sinkholes and caves (karst). Those rocks don't exist outside southeast Minnesota so the rest of the state relies on sandar and shallowly buried sand and gravel aquifers for drinking water supply. Both of these types of aquifer are vulnerable to nitrogen contamination.

Trends in median groundwater nitrate concentration measurements in the Central Sands Region of the MDA Groundwater Monitoring Program have been increasing over the last 30 years, even with the adoption of best management practices.

Source: Adapted from MDA

Nitrate concentration increase over time



Colors indicate data collected from two separate monitoring well networks

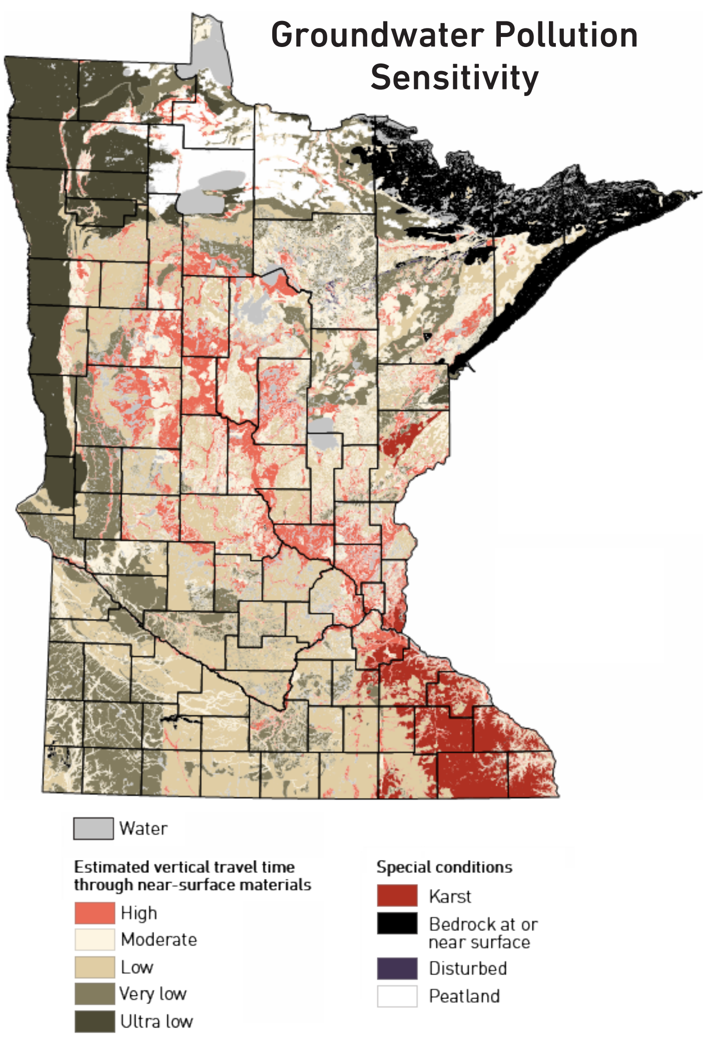
[1] doi.org/10.2489/jswc.69.2.45A

Even other seemingly less vulnerable aquifers may be at risk of nitrogen contamination if they have connections to nitrate-rich surface waters originating from tile drainage. For example, in the Mankato area, surface water recharges bedrock aquifers through the bed of the Minnesota River. Recent water, along with the contamination it carries, is detected in the bedrock aquifers there.[1] In other words, most surface water, including tile drainage water, is on its way to becoming the groundwater that Minnesotans rely on for drinking water.

As a result, private well owners, cities, towns, and other public water suppliers will be on the hook financially and for the long term, and will have to invest in drilling new wells or installing reverse osmosis systems. The treatment cost for an agricultural pollutant is being borne by the homeowner or the water utility rate payer and not by the producer of the contamination.

So far, 15 public water supply systems have had to install nitrate treatment systems with a one-time cost ranging from $7 to $7,600 per household (see table on next page). Private well owners have to spend a few thousand for a household treatment system and then face ongoing costs ranging from $130 to $360 per year.[2] The number of communities treating their drinking water keeps rising; according to MDH, as many as 50 more public water supplies are at risk of needing additional treatment as nitrate leaches deeper into the ground and contamination in drinking water rises. Combined, these public water suppliers serve a quarter million Minnesotans.[3] The University of Minnesota estimates the total cost of the leaky nitrogen system as it relates to drinking water is $6 million per year.[4] Without a reversal in trend, this cost will likely balloon.

When it comes to monitoring drinking water for nitrates, Minnesota is at the front of the pack. Beyond the regular monitoring of public water supplies required by the Federal Safe Drinking Water Act, MDH tests all newly drilled, private wells and MDA has initiated the Township Testing Program for private wells in vulnerable areas. This program provides well owners with information on the safety of their water and the MDA with data on how well they are doing. However, this free testing is not currently available in townships not selected by the MDA. In Brown County, a decision by the County Board to block the program is preventing private well owners from easily learning what is in their wells.[5] All private well owners deserve to know if they are drinking water with agricultural contamination.



Source: Minnesota DNR

[1] files.dnr.state.mn.us/waters/groundwater_section/mapping/cga/c26_blueearth/plate8.pdf
[2] doi.org/10.2489/jswc.63.3.153
[3] health.state.mn.us/divs/eh/water/com/dwar/report2014.pdf
[4] doi.org/10.1126/sciadv.1600219
[5] mprnews.org/story/2018/01/17/free-nitrate-tests-meet-farmer-resistance-in-brown-county

Nitrogen Contamination and Community Public Water Supply Systems (PWS)

The table below lists community PWS with nitrate in their source water equal to or greater than the federal Maximum Contaminant Level of 10 mg/L, and actions taken to provide drinking water that meets that federal standard. Includes cost estimates based on number of households served by PWS.

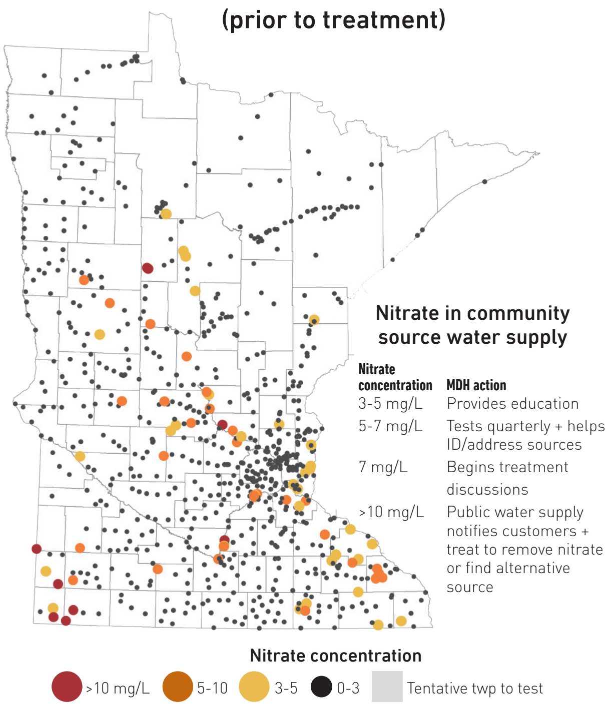
Community PWS with nitrate levels above 10 mg/L (1/1/11-current)	Population (2013)	Past and potential future actions	Est. capital cost per household (2013 dollars)
Adrian	1209	Wells sealed and treatment plant built	$3,300
Brookhaven Development, Shakopee	45	Potential future new well	$3,300
Chandler	270	Potential future hookup to LPRWS*	unknown
Clear Lake	525	Treatment plant to be replaced	$7,600
Cold Spring	4,053	Potential new wells	$1,100
Edgerton	1,189	Treatment plant built	$3,400
Ellsworth	463	Well sealed and treatment plant built	$3,500
Hastings	22,335	Treatment plant built	$410
Leota	209	Interconnection to LPRWS* installed	unknown
Lincoln-Pipestone Rural Water System	12,271	Potential blending wells and treatment plant improvements	$170
Park Rapids	3,709	Wells sealed, new well constructed, and treatment plant built	$3,000
Rock County Rural Water System	2,256	Transmission main built to blend wells	$44
Saint Peter	11,196	Treatment plant built	$1,600
Shakopee	37,076	Transmission main built to blend wells	$7
Sundsruds Court, Menagha	40	Treatment installed	$430

Source: MDH

*Lincoln-Pipestone Rural Water System

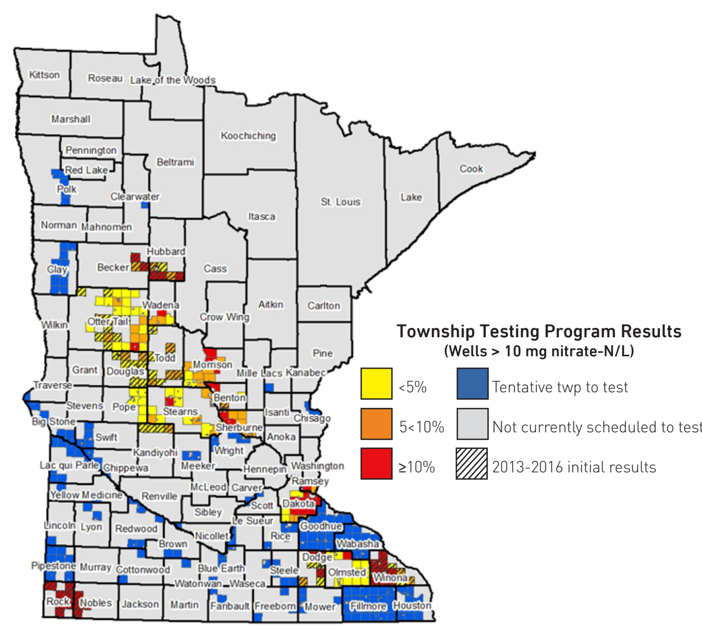
Community Source Water Supply

(prior to treatment)



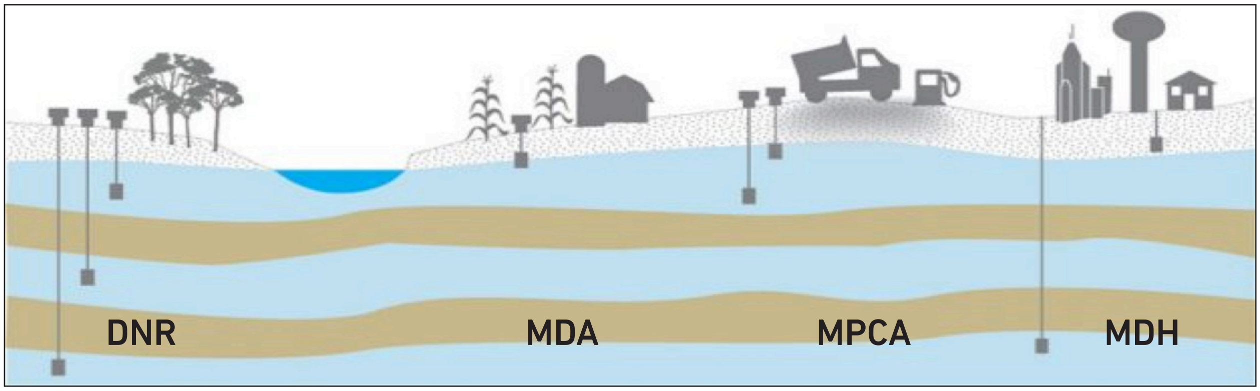
Nitrogen Fertilizer Management Plan

Vulnerable townships being tested by MDA



Statewide nitrate concentrations in community water supply (left) and private wells (right)

Source: Minnesota Environmental Quality Board 2017 Environment and Energy Report Card



Agency authority areas over Minnesota groundwater.

Source: Adapted from Minnesota DNR

State agency roles and authority from Groundwater Act of 1989

The state of Minnesota established "non-degradation" goals for groundwater with the Minnesota Groundwater Protection Act (GWPA) of 1989.[1] This law gave the Minnesota Pollution Control Agency (MPCA) authority over monitoring and preventing all pollutants in groundwater with the exception of agricultural chemicals (i.e. pesticides and nitrate), which are the responsibility of the MDA.

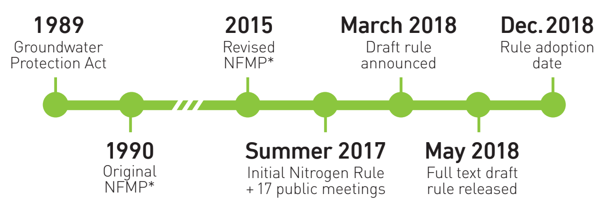
However, when these same agricultural chemicals enter *surface water*, they are no longer the responsibility of the MDA but become the purview of the MPCA. This creates an inherent disconnect between addressing groundwater and surface water contamination and does not reflect the free interchange of groundwater and surface water.

For example, a study by the MPCA found that 72% of the nitrogen load to surface waters originates from agricultural sources. More important for our discussion here is that 93% of this nitrogen passed through groundwater (including tile drainage) at some point before entering surface water.[2]

The roles of the DNR and MDH create even further state agency conflict or confusion over agriculture and groundwater protection. Our groundwater supply (quantity) is managed through water appropriation permits by the DNR, but the safety of drinking water (quality) is monitored and regulated by the MDH. The authorities of these four agencies overlap in some areas but have major gaps in others, making the task of ensuring an adequate, high-quality groundwater supply fragmented at best.

MDA draft rule for nitrogen

To protect groundwater from agricultural contamination, the MDA has recently taken another step in a process that began 28 years ago.



* Nitrogen Fertilizer Management Plan

Authorized by the GWPA, the MDA began to write Water Resources Protection Requirements (WRPRs) in 2017 to address nitrate contamination in groundwater. The proposed WRPRs, known as the Nitrogen Fertilizer Rule, are informed by the MDA's 2015 Nitrogen Fertilizer Management Plan.[3] An initial version of the Rule was discussed at 17 public meetings, engaging 1500 stakeholders and generating 820 written comments.[4] The proposal

[1] revisor.mn.gov/statutes/?id=103h
[2] pca.state.mn.us/sites/default/files/wq-s6-26a.pdf
[3] mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/~/media/Files/chemicals/nfmp/nfmp2015.pdf
[4] mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan/mitigation/~/media/Files/chemicals/nfmp/nitrogenfertrule17.pdf

was unpopular across diverse interest groups. The initial version would have codified practices that most producers already do but that are not effective enough to reverse rising nitrate concentrations in groundwater.[1]

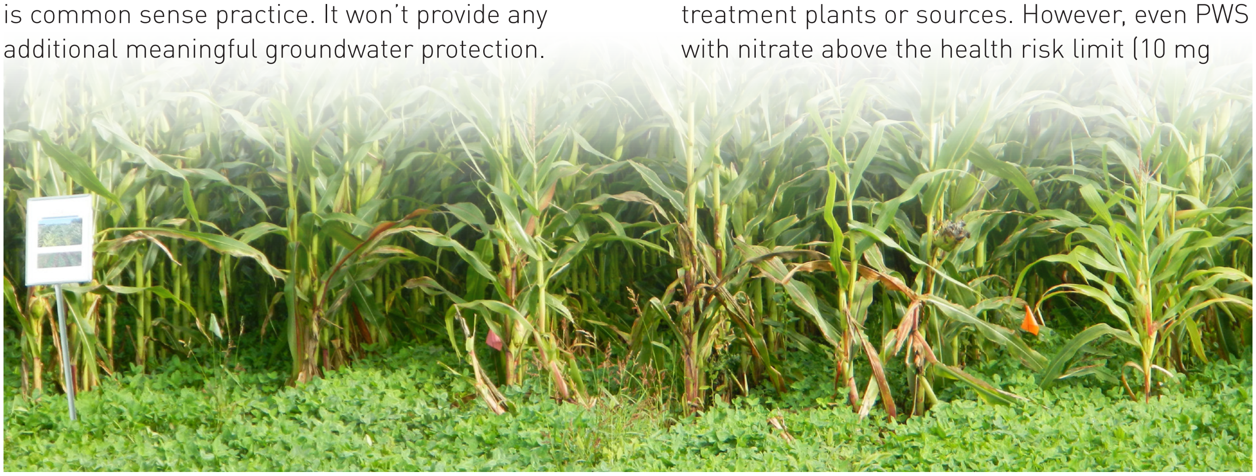
The MDA announced a revised draft of the Rule in March 2018.[2] The full text is expected by May with adoption into rule by December, 2018. We think the new draft Rule could be effective in protecting public drinking water supplies but leaves private well owners without any meaningful regulatory support to protect their drinking water. MDA's current proposal is one step in the right direction, and one step in the other way.[3]

The revised draft Rule has two major parts. Restrictions on fall fertilizer applications in Part 1 of the Rule are a no-brainer; applying fertilizer on sandy soils that have no crops to take it up is not economical and also leads to nitrogen losses to the groundwater. Producers know this and many of them are already following the spirit of this law. A study conducted by the University of Minnesota in 2010 found that less than 3% of farms producing irrigated corn (i.e. those on sandy and vulnerable soils) were making a major application of nitrogen fertilizer in the fall.[4] So Part 1 of the Rule merely cements into law what is common sense practice. It won't provide any additional meaningful groundwater protection.

Revisions to Part 1 of the Rule also exempt part of the state. There are good reasons to exempt certain areas because of differences in local groundwater conditions, climate, and cropping systems. While we largely agree with the map of regulated areas under Part 1 proposed by MDA, we argue that the existing map of Pollution Sensitivity developed by the DNR (see page 20) to estimate travel time from the ground surface to the aquifer is the best one to use when considering the impact of nitrogen fertilizer on groundwater.[5]

Part 2 of the rule protects public water suppliers (PWS) and their rate payers by requiring producers in Drinking Water Supply Management Areas (DWSMAs) to adopt practices beyond the University of Minnesota BMPs.[6] This is a good groundwater protection measure. Although the BMPs have served an important role in preventing our nitrate problem from getting worse, these practices were developed with an economic rather than environmental goal in mind. Restrictions on nitrogen fertilizer applications under Part 2 of the Rule can begin when nitrate concentration in a PWS exceeds 8 mg N/L.

Our hope for this Rule is that it would substantially reduce the financial burden placed on PWS that face major costs to improve water treatment plants or sources. However, even PWS with nitrate above the health risk limit (10 mg



Corn crop was planted into established and strip-tilled field of Kura clover, which fixes nitrogen and does not require yearly re-establishment. Living mulch reduces erosion and nitrate leaching, and promotes infiltration and soil health. Photo: Carrie Jennings

[1] fmr.org/nitrate-rule
[2] mn.gov/governor/newsroom/index.jsp?id=1055-328382
[3] fmr.org/legislative-updates/governor-announces-changes-draft-groundwater-protection-rule
[4] doi.org/10.1016/j.agsy.2012.02.004
[5] dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/mha_ps-ns.html
[6] mda.state.mn.us/protecting/bmps/nitrogenbmps.aspx

N/L) might not be fully protected, if they meet certain conditions for exemption from regulation. Implementation of regulations is also delayed under this rule; it will take at minimum six years from Rule adoption before the MDA will require practices beyond the BMPs.

Although implementation of this Rule will mark the first time that nitrogen fertilizer applications are regulated, it seems likely that very few PWS will realize a benefit before they need to install expensive treatment technology. And the regulation that does occur will be watered down; the best approaches to reduce nitrate concentrations — infiltration of clean water from perennial cover and a reduction in the acreage of nitrogen leaky crops — are not on the table. In the meantime, cities will continue to foot the bill for agricultural pollution in their drinking water.

Additionally, not all PWS will be protected by this rule because the MDH does not have DWSMAs mapped for them all. Out of the total 961 community and approximately 6,000 non-community PWS, only 660 are defined as DWSMAs. The MDH and MDA need to work together to address this issue.

Although Part 2 of the Rule focuses on PWS, it does not provide any protection for private well owners. A report from the Minnesota House of Representatives Research Department estimates that at least 5,500 private wells in areas tested in the Township Testing Program have nitrate concentrations in excess of the health risk limit.[1] An additional 7,000 private wells have elevated nitrate concentrations. Although this is much smaller number of people than those served by public water supply, these individuals also deserve to have safe drinking water.

In the Nitrogen Fertilizer Management Plan, a system of interventions was planned as nitrogen concentration in private wells increased. While this program has not been included in Part 2 of the Rule, the MDA still plans to work with producers on a voluntary basis to improve their nitrogen management.[2] This type of intensive voluntary approach has been successful in the past (see Perham story on page 29) but does not give private well owners the level of protection they are entitled to under state law.

The MDA is clearly charged with protecting all groundwater from agricultural pollutants. The Rule, as currently proposed, falls short. It will not protect all groundwater in Minnesota from degradation because it is limited to certain areas. At a minimum, we must consider the costs that private well owners incur to remove nitrates from their drinking water, and put more effort into getting perennial crops onto our agricultural landscapes. On the whole, this Rule appears to be a symbolic act rather than one designed to fully protect groundwater from nitrate. It might not be wise to spend all of our political capital on an effort that won't get us to our ultimate goal: clean and safe groundwater.

While this process is playing out in the executive branch, the legislature is considering a number of proposals to limit the rule-making authority of the MDA.[3] Despite our objections to the rule, it is not appropriate for legislators to intervene in this agency-driven process.

The State of Minnesota adopted a Nutrient Reduction Strategy in 2014 to address degradation of all water — both surface water and groundwater — because they are intimately connected.[4] One of the multiple goals in the strategy for surface waters is ambitious, but essential: to reduce nitrate loading by 45% to the Mississippi River. The three strategies for surface water are 1) increase nitrogen-use efficiency, 2) increase living cover on the landscape, and 3) improve agricultural water management in both irrigation and drainage. Of these three strategies the proposed Nitrogen Fertilizer Rule primarily focuses on #1. We think this is inadequate and that the other two strategies should also be emphasized equally by the MDA. Without these other two, the proposed efforts of the MDA will be as effective as a three-legged stool.

[1] freshwater.org/wp-content/uploads/2018/03/MississippiRiverGrtr10_2017_cs_updated_memo.pdf
[2] mda.state.mn.us/chemicals/~/media/Files/chemicals/pfmdupdate/2018-02-pfmdupdate.pdf
[3] fmr.org/legislative-updates/multiple-bills-undermine-state-drinking-water-protection-authority
[4] pca.state.mn.us/sites/default/files/wq-s1-80.pdf

For nitrogen fertilizer management, we would also like to see a comprehensive approach similar to the one that California has taken under the Irrigated Lands Regulatory Program.[1] The State of California intends to protect groundwater and reverse trends by strictly accounting for nitrogen applied at the field scale to minimize losses where they start. Producers must keep records (see worksheet at right) on the quantity of nitrogen being applied to their fields and removed as part of the crop when it is harvested. The difference between these amounts can provide a much more accurate estimate of how much nitrogen fertilizer is polluting the environment and give producers direct evidence of the good work they are already doing to protect the environment. A system like this is one of the only ways to quantify the load of nitrate to water resources and is foundationally similar to the rationale used in Total Maximum Daily Load (TMDL) studies for surface water.

NITROGEN MANAGEMENT PLAN WORKSHEET

1. Crop Year (Harvested): ____
2. Member ID# ____
3. Name:

4. APN(s):	5. Field(s) ID	

CROP NITROGEN MANAGEMENT PLANNING		N APPLICATIONS/CREDITS	26. Recommended/ Planned N	27. Actual N
6. Crop		**15. Nitrogen Fertilizers**		
7. Production Units		16. Dry/Liquid (lbs/ac)		
8. Projected Yield (Units/Acre)		17. Foliar N (lbs/ac)		
9. N Recommended (lbs/ac)		**18. Organic Material N**		
10. Acres		19. Available N in Manure/Compost (lbs/ac estimate)		
Post Production Actuals				
11. Actual Yield (Units/Acre)		**20. Total Available N Applied** (lbs per acre)		
12. Total N Applied (lbs/ac)		**21. Nitrogen Credits (est)**		
13. ** N Removed (lbs N/ac)		22. Available N carryover in soil; (annualized lbs/acre)		
14. Notes:		23. N in Irrigation water (annualized, lbs/ac)		
		24. Total N Credits (lbs per acre)		
		25. Total N Applied & Available		

PLAN CERTIFICATION

28. CERTIFIED BY:	29. CERTIFICATION METHOD	X
	30. Low Vulnerability Area, No Certification Needed	
	31. Self-Certified, approved training program attended	
DATE:	32. Self-Certified, UC or NRCS site recommendation	
	33. Nitrogen Management Plan Specialist	

Worksheet required for California farmers under the Irrigated Lands Regulatory Program

Source: Central Valley Regional Water Quality Control Board

Future of fertilizer applications

New technologies collectively known as precision agriculture are rapidly becoming available for farmers to improve the efficiency of fertilizer inputs. With the help of drones, satellites, and autonomous robots we are approaching a world in which producers can shift from uniform applications of fertilizer once or twice per year to daily individualized application using no more or less than is needed for optimum growth and yield.

Data collected by the multispectral sensor on this drone will be used to direct in-season nitrogen fertilizer applications on a farm in southeast Nebraska.

Photo: Laura Thompson, cropwatch.unl.edu/2017/sare-grant-aids-farmers-using-drones-test-n-applications

One example of a groundbreaking precision management tool is a software program developed by researchers at the University of Minnesota.[2] Using imagery from drones, this software is akin to facial recognition for plants.[3] It detects when crops are nitrogen stressed. With technology like this we are approaching a future where each plant can get exactly the fertilizer it needs, maximizing yields while protecting the environment.

This technology is something that both agricultural and environmental communities should invest in and promote. Improving the

[1] waterboards.ca.gov/centralvalley/water_issues/irrigated_lands
[2] twin-cities.umn.edu/news-events/u-m-licenses-technology-monitor-crop-nitrogen-status-ag-tech-firm-sentera
[3] mndaily.com/article/2018/03/n-umn-drone-tech-may-prevent-nitrogen-contamination

efficiency of nitrogen applications means that less nitrate will accumulate in groundwater. It will probably be five to 10 years before these products become mainstream and only then will we learn about their real world economic and environmental benefits.

How potent is a pesticide cocktail?

If there is nitrate in the water, we can assume other agricultural chemicals are there as well. It is cheaper to test for the presence of nitrates so that is usually done during initial screening.

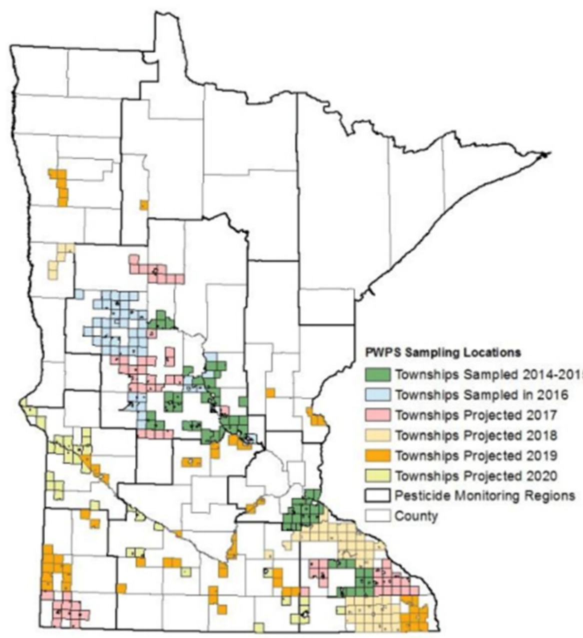
MDA surveys of high-nitrate private wells give us a sense of the relationship between nitrate concentrations and the detection of pesticides; 97% of wells with nitrate levels greater than 10 mg/l had detectable levels of pesticides. Detection doesn't necessarily indicate unsafe water, just as non-detection doesn't necessarily indicate safe water. In many cases, we simply don't have enough epidemiological information to make these determinations.

Freshwater has been convening groups and making recommendations for strategies to manage agricultural chemicals since 1986. The MDA now has one of the most comprehensive groundwater pesticide monitoring programs in the country. In 2016, more than 1,500 groundwater samples were analyzed for 125-150 different pesticides or degradates. In the second round of testing in the Township Testing Program, private well owners with water that tested high in nitrate concentration had the opportunity to have their water tested for pesticides. Of those wells that were sampled a second time, 76% had at least one pesticide detected.[1] Monitoring results are shared with the MDH for cumulative risk assessment.

Although there is a drinking water standard for nitrate, the MDH does not have Health Risk Limits[2] for all pesticides or the chemicals that form as they degrade. This is a problem. We also don't know what it means to have three, six, or eight chemicals together in the same cup of tea or steamy shower spray. No one knows the risk that rural residents may face by drinking trace amounts of this cocktail. Dose and consumption habits make a difference. So does time.

Ideally we would have something akin to a fish advisory limit for rural drinking water. How much water should a person — pregnant, immune-suppressed, or otherwise — consume from an untreated or minimally-treated rural water supply? How does drinking this increase one's risk of getting ill or dying prematurely? The MDA, MDH, and MPCA are collaborating to develop recommendations in the absence of federal leadership on the topic. But in the end, we are left with a lot of data and many questions about the cocktail we are concocting.

The good news is that the same strategies to address the nitrogen problem should reduce pesticides in groundwater, too.



Areas offered or projected to be offered private pesticide well sampling by 2020
Source: MDA

[1] mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/pwps/~/media/Files/protecting/cwf/pwps/allcountypwpsfs0717.pdf
[2] health.state.mn.us/divs/eh/risk/guidance/hrltype.html

Managing manure

Using manure as an organic source of nitrogen represents a potential savings to a producer and is also a way to use waste from animal agriculture. However, manure may contain bacteria, viruses, and protozoa as well as the pharmaceuticals that have been fed to the animals. These contaminants are being incorporated into the soil and shallow groundwater along with the beneficial nutrients in manure. Therefore, this cannot be considered as a 100% environmentally-friendly practice without further analysis.[1]

These contaminants get spread, sprayed, or knifed in along with the manure and we end up drinking, breathing, or bathing in them. We know very little about their impact on humans, animals, and disease resistance but evidence about the increase in antibiotic resistant bacteria is alarming. We need to pay close attention to the environmental and health impacts of this practice of broadcasting pharmaceuticals and pathogens.

First generation agriculture

The current division of agency authority leaves a gaping hole when it comes to groundwater protection in areas that are being converted to agriculture *for the first time*. The evolving situation in the Pineland Sands in north-central Minnesota, where forests are being cut down to plant potatoes, illustrates this point. If we immediately collect and compile baseline data before the conversion to crops is complete, this situation offers a rare chance to find ways to avoid damages to water quality down the line.

The MDA, R.D. Offutt Company, and Central Lakes College have begun this process by establishing a long-term monitoring study of nitrate leaching under a field recently converted from pine forest to potato production in Byron Township, Cass County.[2]

Yet in our central sandplains, the DNR continues to issue irrigation-well permits, mainly with an eye on volume and the effect of drawdown on wetlands, lakes, and cold-water streams. Fields are being chemigated; herbicides, pesticides, and fungicides are applied in the irrigation water. This water leaches into the soil and shallow groundwater, though some of the chemicals go into the atmosphere and some are taken up by plants. Pumping from the deeper irrigation wells circulates the chemicals more quickly and possibly more deeply into the aquifer.

The MDA licenses those who apply agricultural chemicals and samples for the presence of those chemicals in groundwater. However, they are missing the opportunity to prevent groundwater contamination at the outset. In these irrigated systems overlying vulnerable groundwater, the supply and quality of water is inextricably linked.

Slash piles of a jack pine forest during conversion to a potato field near Huntersville, Minn.

Source: Minnesota DNR

[1] extension.umn.edu/agriculture/manure-management-and-air-quality/manure-pathogens/best-management-practices/#introduction
[2] mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/byrontownship.aspx

The current authority of state agencies doesn't equip them to collaboratively protect clean groundwater, only to identify contaminated groundwater and warn people about drinking it. Gaps in agency authority and lack of communication between agencies are impeding a coordinated approach to maintaining and improving groundwater quality in areas of the pristine headwaters region of the state that are being converted to cropland. Waiting for pollution to happen is not a solution.

Understanding decision-making on farms

Although producers and environmentalists have many opportunities to collaborate on common goals, this can be challenging to do without considering the decision-making process used by producers. That process is shaped by a number of factors including economics and global market forces; tradition and unquantifiably valuable local knowledge of soils and fields; government incentive and insurance programs; new technologies and tools promoted by farm input and equipment dealers; and desire to do the right things for their farm and community.

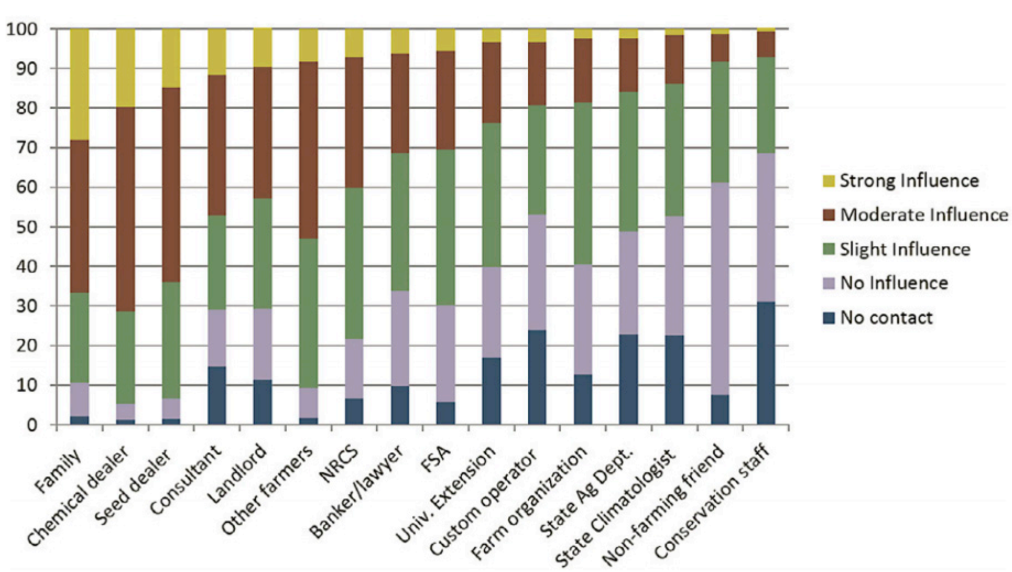
Of all of the influencers in the agri-business ecosystem outside of the immediate family, those who most strongly leverage decision-making are retailers, crop consultants, and those with a direct financial connection to the operation including bankers, landlords, and government agencies that provide subsidies and insurance to farms.

Ranking last in terms of influence are the organizations that have typically been relied upon to deliver impact on conservation and environmental goals. When it comes to changing farmers' choices, University of Minnesota Extension, state agencies, and conservation or environmental organizations rank among the least effective groups. This should not be surprising since the goals of these organizations often conflict with those of the producer trying to make a living.

Better outcomes for water quality may be realized if organizations collaborate with the real influencers and decision makers, and learn to speak their language. To communicate directly with producers, conservation and environmental organizations need to recognize the economic and social dimensions of the producers' decisions. This alone might open new dialogues that will lead to mutually agreeable solutions to agricultural water-quality problems.

The town of Perham, Minn. is one place where common ground was found through dialogue and

Influences on agricultural practices and strategies

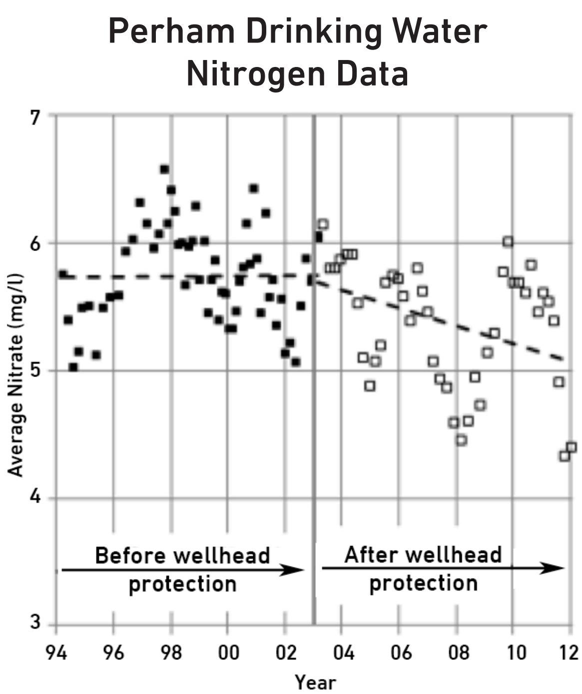


Results of a survey of corn producers in the Midwest on how others influence their management decisions.

Source: doi.org/10.2134/jeq2015.02.0078

has been effective at reversing the trend of increasing nitrate concentrations in groundwater.

"Farmers and water resource managers in Perham, however, took a different approach than the all-too-common finger pointing. In response to the discovery of nitrogen contamination, a group of city officials, staff from the local conservation district, farmers, members of the agribusiness community, concerned citizens and the Minnesota Department of Agriculture decided to go beyond finger pointing. Instead, they held a series of meetings in the early 2000s that focused on both securing clean drinking water and ensuring a strong agricultural economy, and that were rooted in the context of local conditions. In doing so, they found that what at first may seem like an irreconcilable difference can actually be resolved when the opposing sides look for common ground — offering a potential model for other communities dealing with conflicts between farmers and citizens." [1]



A moving average of nitrogen in community wells that historically have tested high in nitrogen

Source: MDA

[1] ensia.com/articles/nitrogen-pollution

The agricultural management practices implemented in the areas around Perham were not themselves unique or exceptionally effective. The key to finding a solution was having environmentalist and conservation groups communicate with producers to understand their economic constraints. As a result, nitrate concentration in Perham's drinking water has declined over the past two decades. Strategic conservation among all interested parties helped them find solutions that protect the community's groundwater.

Perception problems

In early 2018, Freshwater partnered with the East Otter Tail SWCD to meet with producers and learn more about their current irrigation and nitrogen management practices and what practices they hope to try in the future. Our full report includes a few key findings worth sharing here. The first, and perhaps most important finding is that producers are already using a variety of BMPs to meet the unique needs of their fields, and they are using them because they make both economic and environmental sense. Secondly, of the major barriers to future progress that producers identified — assistance, financial support, information, markets, perception, and regulation — perception is by far the most important to them. They are frustrated with the persistent narrative that they are neglectful or ignorant of environmental concerns. At the same time, they understand that more can and should be done to protect groundwater. To make the most progress on improving water quality, we need to recognize the work producers are already doing so we can help them improve practices on their fields.

New cropping systems and alternative markets

Even perfect timing, rate, and placement of nitrogen fertilizer won't stop all the leaks in the current cropping systems. For a good portion of each spring and fall, large portions of our landscape are bare. Without actively growing plants that have deep roots to scavenge excess nitrogen, nitrate will leach into the groundwater. This bare-season leaching alone accounts for a sizable fraction of nitrogen losses and may be enough to degrade groundwater even with the best in-season management practices. Stopping the shoulder season portion of the leak will rely on system modifications: cover crops or winter annual crops added into current rotations or a switch to new perennial crops.

Cover crops are grown not to be sold, but to retain nutrients in the soil and build soil health. Minnesota producers are becoming more interested in cover crops. However, our current climate makes their successful addition to the crop rotation a challenge; on average there isn't enough time between the primary crop harvest and the first frost to establish a cover crop.

Winter annual crops, such as Pennycress and Camelina, have similar benefits to cover crops and also have the potential to be marketed and sold for a profit. Many of the winter annuals being developed are oil seeds that can even be used in jet biofuel production.

Perennials, on the other hand, directly replace acreage that would otherwise be used to grow corn, soybeans, or some other commodity crop. Traditionally, programs like the Conservation Reserve Program have been a source of government subsidies to support the environmental benefits of perennial landscapes.

Alfalfa is perennial crop commonly grown in tandem with dairy or beef operations. Kernza, the perennial cousin of our current wheat crop, is getting a lot of attention for its potential to expand the footprint of perennial crops in Minnesota and become a component of the consumer food system. The University of Minnesota through its Forever Green Initiative is playing a big role in developing these new cropping systems and leading the way forward on reimagining how our agricultural landscapes could look.

Cover crops and perennial cover are much more effective at reducing nitrogen losses than the 4R BMPs. A recent study found that nitrogen load reductions of 30% and 90% could be expected from cover crops and perennial crops compared to 15% for nitrogen fertilizer management alone.[1]

Cover crops and perennial cover are effective but expensive practices; a recent report by the Board of Water and Soil Resources, *Working Lands Restoration Feasibility Study and Program Plan*,[2] found that growing Kernza and cover crops in a corn-soybean rotation would require subsidies of as much as $117 and $39 per acre, respectively. The cost of switching cropping systems would go down if only marginal acres were converted and could reach break-even profitability.

To make these environmentally-beneficial cropping systems both profitable and viable, we need to develop new markets. Consumers, agribusiness companies, producers, and watershed planners all have a role to play in making this happen. We can begin by asking for and purchasing products that are certified *clean-water friendly* in the same way *organic* and *non-GMO* have become must-haves for savvy shoppers. Agribusiness companies can work to develop new commodity oils and bio-energy fuels from winter annuals and perennial crop and incorporate perennial grains such as Kernza into animal and human foods. Producers can continue seeking more information on these new cropping systems and investigate which of them could improve the sustainability of their operations. Watershed planners at the state and local level can focus subsidies for new cropping systems in vulnerable areas, such as DWSMAs in areas at high risk of nitrate contamination. The new Nitrogen Fertilizer Rule also focuses on DWSMAs

[1] doi.org/10.1016/j.jenvman.2017.11.051
[2] bwsr.state.mn.us/planning/WLWRP/WLWRP_Rpt_MN_Legislature_2018.pdf

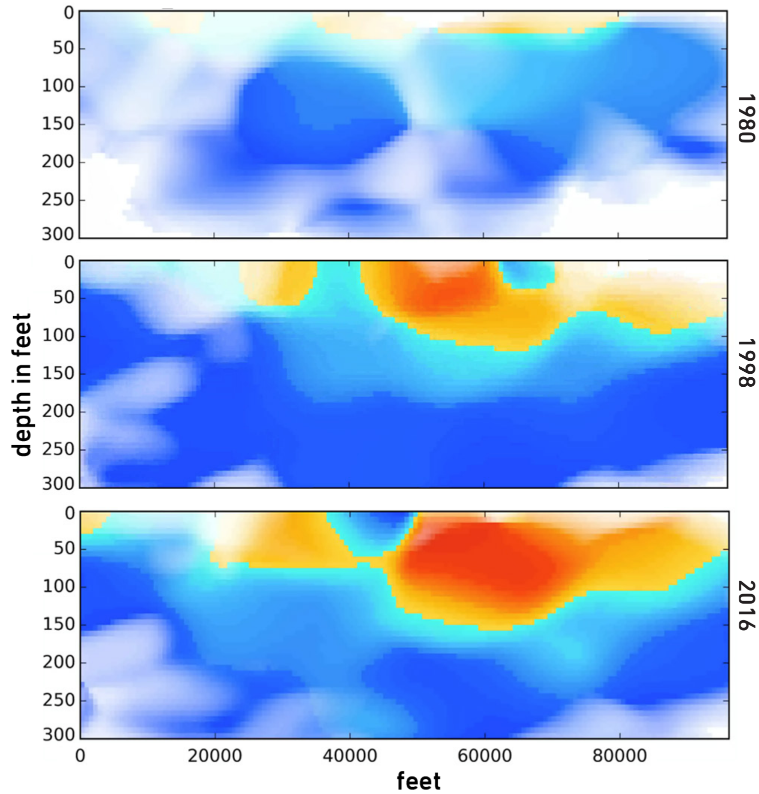
so there is synergy in these two approaches, both for the bottom line of producers and the environment.

Perspective on the path forward

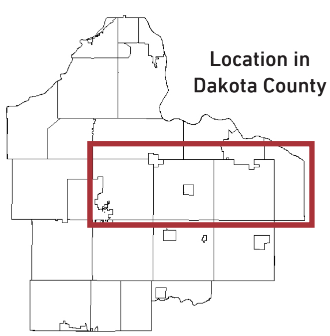
Producers should keep implementing practices that make good economic as well as environmental sense. However our traditional strategies to manage nitrogen fertilizer — collectively known as the 4Rs — have not reversed the trends or moved us closer to clean water. In fact, because it takes years to decades for surface water to reach the deep groundwater, higher nitrogen concentrations will continue to move into deeper groundwater, according to data compiled by Dakota County.

The safety of rural residential drinking water, nitrate levels, and the suite of environmental indicators Minnesotans care deeply about — including pollinators, carbon, and sediment — are still moving in the wrong direction. The path forward requires a shift in the cropping system on a substantial number of acres to achieve the desired outcome we all share: a healthy rural environment and economy.

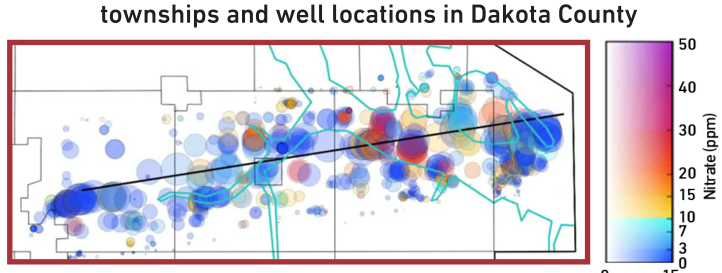
Nitrate is moving deeper in Dakota County groundwater



The pulse of high nitrate water is moving from the surface into deeper groundwater. Concentrations in domestic wells in the county will continue to increase, even with significant fertilizer reductions on the surface. Blues are less than 10 ppm, yellows to reds are above10 ppm. Color saturation is proportional the number of local samples on which the estimate is based.



Cross section line, townships and well locations in Dakota County



Source: Time Lapse Movies of Nitrate Concentrations in Dakota County Aquifers William Olsen, Dakota County Environmental Resources Department, presented at U of M Water Resources Conference, 2017, ccaps.umn.edu/documents/CPE-Conferences/Water/2017_WaterResources_Brochure.pdf

Recommendations for water quality

Incentivizing agricultural practices that make environmental sense while facilitating a transition to cropping systems that protect groundwater quality will save the state money and result in a healthier rural environment and economy.

Minnesota Department of Agriculture

- Develop a nitrogen-accounting program for producers to identify what leaves their fields
- Use the existing DNR Pollution Sensitivity Map to implement the Nitrogen Fertilizer Rule
- Continue researching and implementing three approaches to reduce nitrate leaching: 1) efficient use of nitrogen; 2) irrigation water management; 3) living cover to reduce nitrogen loss during fallow seasons
- Focus on Drinking Water Source Management Areas (DWSMA) to develop innovative strategies that address nitrogen contamination
- Work with the MDH to develop DWSMAs for all public water supplies
- Include protections for private well owners in the Nitrogen Fertilizer Rule

Minnesota Department of Natural Resources and Minnesota Department of Agriculture

- Protect relatively uncontaminated areas like the Pineland Sands and Mississippi River headwaters by compiling baseline data before conversion to row crops is complete. If negative trends are identified earlier they can be addressed more affordably

Minnesota Department of Health

- Coordinate approach to groundwater contamination to help the MDA create a clear assessment of what the groundwater data tell them, and how to measure success or failure with pesticides
- Offer guidance to county health departments so they can help private well owners obtain safe drinking water

Board of Soil and Water Resources

- Work with the MDA to collaborate on nitrogen rules by establishing some recommendations in the Working Lands Program on Drinking Water Source Management Areas

University of Minnesota Extension

- Direct outreach programs towards key influencers of agricultural decisions, such as retailers and crop consultants, to promote conservation as potential business opportunity
- Continue development of Forever Green Initiative crops and pursue market-driven opportunities to expand their impact

Legislature

- Direct the legislative auditor to evaluate the budgetary threat of ballooning treatment costs for removal of nitrate from drinking water supplies
- Clarify roles and enhance coordination between the five executive branch agencies using the Legislative Water Commission or similar effort. Current gaps in authority impede the protection of clean groundwater
- Authorize a study bill to understand the impact of manure application on chemicals of emerging concern such as antibiotics, hormones, and pathogens in groundwater
- Define level of the state's financial involvement when private and public wells are impacted by agricultural chemicals

Producers

- Introduce cover crops into existing crop rotations and convert marginally productive areas to low nitrogen or perennial crops
- Adopt precision agriculture management tools to further improve nitrogen-use efficiency
- Develop a nitrogen management plan that accounts for inputs and outputs

Consumers and well owners

- Demand a clean-water branding of locally produced agricultural products
- Request that your grocery stores and food companies support water-friendly agricultural practices
- Have your well water tested and report results to your county
- Get to know a farmer, and learn about the work they are already doing to protect drinking water

Closing thoughts

SUMMARY Reversing agricultural impacts on groundwater requires more than minor alterations to current practices. State support to encourage new practices is essential during the transition to a more sustainable agricultural system.

Right now the state's water quality strategy appears to involve telling rural residents with contaminated water to spend thousands of dollars on a household reverse osmosis system. The strategy for over-subscribed aquifers is to tell irrigators that they all have to cut back on water use when they need it most. This is a deeply unsatisfying status quo.

Minnesota has a tough row to hoe. The mounting damages to groundwater in agricultural areas of the state are consuming too many of the state's limited natural resource dollars. These costs are not being paid by the producers and it is politically difficult to shift the costs to them because they are barely breaking even. We need ways to make farms profitable that also improve groundwater quantity and quality. We can't go back to how things used to be, so finding a new path forward is key.

We need to mimic the functionality of the natural landscape and be creative about solutions that work for everyone. The livability of rural areas depend on it. Perennial crops that use fewer inputs need to increase in tandem with the markets that buy them, a tricky transition that the state can fund in the short-term.

We really have no choice.

While broader, paradigm-changing efforts are underway, Minnesota can get started by focusing on those areas already seeing negative impacts. By keeping local needs and the real constraints of the agricultural systems in mind, creative local solutions may emerge. Successful efforts could then become case studies for future shifts in the broader agricultural system of Minnesota and the upper Midwest.

An analogous, seemingly impossible environmental problem was the ozone hole. How could a society possibly live without aerosol containers? Well, we have; the ozone hole is starting to shrink. Researchers estimate that by 2070 it will be back to the size it was in 1980 when the world started restricting the use of ozone-depleting chemicals like freon. Slow but real progress is being made. Ninety years to fix the ozone hole. Can we afford to wait that long to improve groundwater in Minnesota?

By finding locally-beneficial solutions that balance economic considerations with environmental priorities, such as converting fields from row crops to perennial vegetation that scavenges nitrogen, we can expect measurable improvement within a decade, in part because fresh water continues to fall from the sky. By making wise choices at the grocery store and off the menu we can do our part to influence what is being grown.

Minnesota, we can do this.

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