Legislative Water Commission- 2019 Legislative Recommendations:
Keeping Water on the Land
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DRAFT for Discussion
JRS

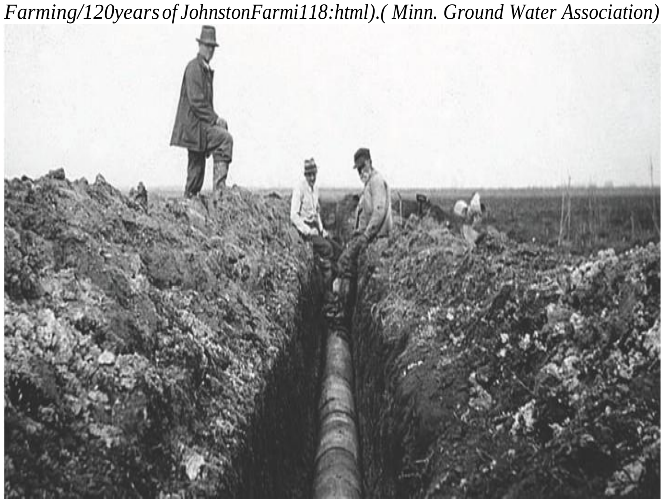
This draft document primarily is based on several sources that include the documents listed below. The draft document has not been fully attributed at this time.

- *Minnesota Ground Water Association, 2018; Drain Tiles and Groundwater Resources: Understanding the Relations, a White Paper, 35p*
- *Minnesota Board of Water and Soil Resources, Drainage Working Group: various papers and documents*
- *University of Minnesota, 2015; Fields to Streams: Managing Water in Rural Landscapes, University of Minnesota Water Resources Center and Extension, University of Minnesota, Extension, Water Resources Center, 99 p.*

Issue Summary and Draft Recommendations

Throughout our state's history, our residents have worked to change how water flows-- building dams and dikes, straightening and dredging channels, armoring streambanks, digging ditches, installing subsurface tile, and constructing storm-sewer systems. The most extreme hydrologic alterations are the construction of impervious surfaces such as roads and buildings in our cities. However, the most widespread alteration of our hydrology has been the conversion of native prairie to farmland and the construction of the network of drainage ditches and subsurface tile that have been essential for intensive crop production and transportation infrastructure. Altered hydrology occurs in both urban and agricultural portions of the state and hydrologic alterations are locally more extreme in our cities and towns. However, the total area of affected lands is greater in agricultural portions of the state. In both areas, we need to increase efforts to retain water on the land in order to improve natural streamflow and to improve water quality and aquatic ecology. The question is this: What best management practices are appropriate in specific landscape settings within watersheds, and how can they be encouraged to improve our water resources?

Installation of clay tile on the Johnston form, circa 1938 (photo from http://www. nejohnston.org/wej/120 Years of Johnston Farming/120years of JohnstonFarmi118:html).(Minn. Ground Water Association)



Background: In order to enable and enhance agricultural production, transportation, and economic development, the construction of drainage ditches began before Minnesota became a state. The ditches connected the natural stream network to previously unconnected depressions and wetlands and lowered the water table near ditches. Precipitation stored in depressions and soil around them was conveyed to streams and rivers. Many streams were straightened and enlarged to increase transport capacity. Each county has records of the public ditch systems, however no statewide record and map of historical ditch development has been compiled. The most active ditch construction occurred in the period from 1900 to 1929, with the decade of greatest drainage being 1910 to 1919. There was little new drainage installed during the dry years and economic depression of the 1930's. Drainage activity reemerged after World War II, driven by economic factors and periods of above-average precipitation.

The network of ditches for surface drainage has been augmented by installation of subsurface drainage tiles originally fabricated from clay or concrete. More recently, perforated plastic pipe is used instead of clay or concrete. Initially, tile lines were installed to drain individual wet areas that were not intersected by the ditches. With the development of the less expensive plastic drainage pipe and mechanized installation equipment, systems have expanded by patterned installation of pipe to systematically remove water from entire fields. Unlike the public ditch systems, there has not been a county-maintained record of subsurface field drainage because those systems are installed by individual landowners and permits are not needed. Subsurface field tile installation in southern Minnesota advanced throughout the 1900s and continues today. Systematic field drainage in the Red River valley was largely limited to surface drainage by ditches until about 2005, when subsurface system installation began at a rapid rate.

<u>Benefits and Impacts of drainage</u>: Historically, poorly drained soils were saturated or flooded after spring snowmelt, preventing timely farm operations such as tilling and planting. Installation of agricultural drainage, both surface ditches and sub-surface drainage accelerated transport of water from farm fields and resulted in greater crop yields. Agricultural drainage has provided other benefits such as preventing crop drown-out, aerating the soil for improved plant growth, limiting surface runoff and soil erosion, and allowing farmers better access to croplands. Without agricultural drainage on much of Minnesota's croplands, it would have been difficult to realize high-enough crop yields needed for farmers to have economically viable returns on their investments.

While drainage of Minnesota's croplands provides benefits, several environmental concerns are associated with agricultural drainage. These include wetland loss, habitat loss, and degradation of downstream water quality and reduced potential for groundwater recharge. Early agricultural drainage efforts (pre-20th century) led to the disappearance of much of Minnesota's natural wetlands. The increased focus on preventing or mitigating wetland loss over the last 50 years has helped curtail further losses, even as agricultural drainage proceeds. Prior to establishment of Minnesota statehood, wetlands accounted for more than 10 million acres in Minnesota, including prairie wetlands, peat-lands, and forest wetlands that comprised approximately 19 percent of the total land area. In 2018, only half of Minnesota's pre-settlement wetlands remain, mostly in parts of the State that have not experienced widespread drainage.

<u>Other consequences of tile drainage:</u>

Reductions of the time water is being stored in the soil: Only drainable water is removed by tile and ditches. The amount of plant available water (i.e., water held by soil particles against the pull of gravity) is not affected by artificial drainage systems.

Changing pathway of water over land: Some ditches and tile link streams to depressions (potholes) that were previously not connected.

Reducing overland flow: This occurs if water moves through soil and subsurface tile. Overflow still occurs on tiled land if surface soil structure is poor, blocking infiltration, or if the soil is saturated.

Decreasing evaporation-- by removing areas of standing water.

Increasing annual transpiration—when rooting depth and productivity are increased.

Increasing the total amount of water that reaches streams (annual yield). Models show that tiling increases the annual amount of water leaving the field.

Reducing, delaying and extending peak flows in streams occurs after precipitation or a snowmelt event (if water is moving through tile systems instead of overland). Water takes longer to travel through soil to a tile system than to move overland or through ditches. This means rainfall will reach streams later than if it only flowed overland. Soil continues to drain long after an event, so elevated stream flow lasts longer than if the rain all reached the stream overland.

Water-Quality Degradation: Water-quality monitoring has shown that drainage, in particular the practice of subsurface drainage, provides a direct flow path for moving water to ditches and streams. The negative consequences of drainage on surface water quality are well documented. These impacts include: excess nutrients, high sediment levels, flooding, property loss, and habitat loss. The last half century has seen substantial increases in the volumes of water delivered to streams. This has resulted in increased stream widths due to bank erosion, increased amounts of sediment transported in streams from field, and streambank, bluff and ravine erosion. Sources of sediment primarily are the result of greater flow of water to, and in, streams and rivers. To protect streams, the land, wildlife, and water quality, more water needs to be retained on the land and more water needs to be transpired by plants or infiltrated to groundwater, in cities and on farms by using new and existing land and water management practices.

Groundwater recharge: The connection of hydrological effects of agricultural subsurface drainage on groundwater recharge and aquifers is not well-established. Agricultural subsurface drainage intercepts infiltrating water below croplands and directly discharges the water to nearby surface waters. However, the size of the water balance shift comparing drained water, evaporated water, run off and drainage has not been well characterized.

Other effects of drainage on underlying aquifers also is not well known. A basic understanding of aquifers and their recharge is necessary to connect any hydrological effects from agricultural drainage to groundwater.

Urban Storm Water Retention: Water storage in urban areas can reduce peak flows in streams. Peak flows drive erosion. Storage is especially effective in small watersheds that have a high sediment yield per amount of stream flow. Ravines and large gullies often supply large volumes of sediment eroded per unit of stream flow. Bypassing these areas or reducing and slowing the water flow can be effective in terms of cost per unit sediment reduced. However, the impact of stored waters in urban areas is not well established. We do not fully understand if groundwater recharge is increasing or decreasing. We also do not understand the impacts that storage is having on groundwater quality.

Strategies for reducing the Impacts of Drainage

Land and water management's practices have potential to protect and to improve water quality by modifying water use and flows. The practices are most effective when they are combined is sequences in a watershed. Individually or when combined, these practices have multiple impacts that include: improved soil structure and water holding capacity; reduced channel erosion; improved water quality and in-stream habitat; and reduced flooding. Ponds and wetland restoration for water storage in agricultural drainage systems improve drainage system efficiency. They dampen peak flow, and reduce the size requirement for ponds and ditches downstream. Practices that add perennial vegetation or that diversify channel structure also reduce channel erosion and create habitat.

These practices can be characterized according to where they are located in the various landscapes and according to the effects that they have on the hydrology of a watershed. In-field crop and soil management is appropriate in areas of intense agriculture. They improve watersheds by increasing transpiration, water infiltration, soil-water holding capacity as well as the resistance to soil erosion. Treatments in drained landscapes include increased drainage-management practices coupled with water treatment and retention/detention structures, constructed wetland, ponds, irrigation reservoirs, or modified ditch channels. Treatments that are applicable to sloping lands include grassed waterway, fitter strips buffer strips, terraces and water and sediment control basins. Riparian area modification and orientation, coupled with stream channel protection are most applicable near the outflow areas of watersheds. Because treatment methods need to be designed for local landscapes, climate and cropping systems need to be sited in ways that fit individual watersheds. The costs for the practices differ considerably with size, location and other factors.

Buffers: Buffers along streams, rivers and ditches have potential to slow water, sediment and nutrient delivery as well as increasing biological habitat. The 2017 Legislature directed the Board of Water and Soil Resources (BWSR) to coordinate the Drainage Work Group to evaluate and develop recommendations to help Minnesota drainage authorities accelerate the acquisition and establishment of buffer strips and alternative practices adjacent to public drainage ditches and associated compensation of landowners. The impetus for this action was the 2015 Buffer Law, which required landowners to establish buffer strips, or alternative practices, along all public drainage ditches. Recommendations were developed by a Project Advisory Committee organized under the auspices of the Drainage Work Group with BWSR staff support. The Advisory Committee evaluated impediments to drainage system acquisition and establishment of buffer strips and formulated actions for statutory, funding, and administrative policy changes, and outreach. The report was approved by the Drainage Work Group, accepted by the BWSR Board, and transmitted to the Legislative Policy Committees. Recommendations were categorized according to the type of action required and grouped according to the potential for the recommended actions to accelerate the acquisition and establishment of drainage system buffer strips, alternative practices and landowner compensation, or for their potential long-term benefits.

Soil Management involves enhancing the ability of the soil to infiltrate and store precipitation. Soil and crop management in agricultural fields affects infiltration rates and water holding capacity through effects on soil structure and soil organic matter.

Increasing Transpiration involves managing the amount and distribution of crop transpiration throughout the year. Transpiration is the largest user of precipitation water, and its timing relative to rainfall distribution has a great influence on how much surplus water will move off the land.

Managing Overland Flow involves the management of overland flow with crop residue, contour farming, and vegetated flow pathways like waterways and filter strips that slow, filter, and partially infiltrate surface runoff.

Subsurface Drainage management involves addressing subsurface drainage flow by sizing, depth, and spacing drainage pipe to control rates of drainage water leaving the field. Control structures can also be installed in the drainage system to allow temporary water storage for later crop use or timed release.

Water Storage: Increasing water storage, involves enhancing natural water storage in wetlands and other depressions, as well as storage with constructed wetlands, terraces, ponds, water and sediment control basins, down-sized culvert retention, weirs, and large detention basins.

Streambank Protection and Riparian Area Restoration: Establishing measures to protect channels and restore riparian areas.

Green cover crops and Agricultural Alternatives to corn and soybean rotations have great potential to slow the delivery of water, sediment and nutrients to our ground and surface water. The challenge is in finding crops that can compete with corn and soybeans economically.

Recommendations

There are many water-related concerns associated with water drainage and water retention. Rivers and streams integrate the effects of these management practices. Precipitation, vegetative cover, land management, geology, soils, and landscapes characteristics all influence our rivers. In combination with other watershed characteristics, the effects of changes we have made to natural drainage conditions magnify downstream in our rivers. These effects include excess nutrients, high sediment levels, flooding, property loss, and habitat loss. During the last half of the century, we have experienced increases in the volume of water in streams, the width of stream channels, and the amount of sediment being transported from fields, streambanks, bluffs, and ravines, primarily in southern Minnesota. The sources of sediment are primarily the result of greater stream and river flows. Increases in channel-shaping flows are related to changes in precipitation, decreases in transpiration, changes in agriculture, decreases in surface water storage due to drainage, reduced evaporation as well as changes in soil water holding capacity. To protect our rivers, farms, and wildlife, more water needs to be stored and slowly released using land and water-management practices. Better water management can reduce erosion and sediment deliver as well as reducing nitrate-nitrogen and phosphorus. This will, in turn, improve our streams and rivers. Changes in land and water management have potential to protect and to improve downstream conditions by modifying water quality and flow. As a state we need to determine how best to apply these management practices and how to incentivize them to maintain the productivity of our agricultural and urbanized lands.

Draft Recommendations: Some critical knowledge gaps exist in our understanding and management of water management at watershed scales:

1. ***The overall extent of drainage is needed. Direct estimates of the extent of subsurface drainage do not exist in Minnesota. However, several indirect methods could be utilized to estimate the extent of surface drainage statewide.***
2. ***Fund a cost/benefit/return on investment analysis of conservation drainage-management practices***
3. ***Create an organizational structure, similar to the Drainage Working Group, that encompasses all conservation- management practices***
4. ***Quantify the extent and distribution of open-tile inlet structures across the state and create incentives to replace them with alternatives***
5. ***Effects of drainage on underlying aquifers is unknown. A basic understanding of the impact on unconfined, and confined, aquifers is necessary to quantify the effects (quantity and quality) of agricultural drainage on shallow groundwater. This should include an evaluation of the effects on groundwater recharge.***
6. ***The effects of urban storm-water retention systems and rain gardens needs to be evaluated with respect to the quantity and quality of ground water***
7. ***An improved understanding of historical water-balance shifts from pre- to post-drainage periods is needed to understand long-term implications on groundwater recharge. More direct field-scale studies and modeling studies are needed to characterize water budgets for fields with subsurface drainage.***
8. ***Existing tools and systems need to be applied and used to identify the appropriate best management practices at landscape and watershed scales***
9. ***Utilize the one-watershed/one-plan process to locate and to implement best- management practices, within watersheds, at appropriate places and scales***
10. ***Evaluate the effects of drainage on by wetland systems***
11. ***Design programs to quantify potential problems of emerging contaminants in urban storm water retention basins***
12. ***Promote the role and importance of the relationship between healthy soil and healthy water. Establish programs to improve soil health, aimed at increasing agricultural productivity and water retention***
13. ***Support the recommendation of the Drainage Working Group***
14. ***Expand the responsibilities of the Drainage Working Group to include all drainage and water retention activities, rural and urban***
15. ***Quantity and map areas of deep aquifer recharge as areas that need to be protected from chemicals introduced as the result of drainage and water retention activities***
16. ***Encourage programs to maintain and upgrade rural ditches and culverts that reduce erosion and encourage fish passage***

Expanded Discussion: Draft Legislative Recommendations: Keeping Water on the Land

History of Drainage in Minnesota: Draining excess water from the land has been essential to the agricultural and urban development of our state. Throughout our state's history, people have changed how water flows by building dams and dikes, straightening and dredging channels, armoring streambanks, digging ditches, installing subsurface tile, and constructing complex storm-sewer systems. The most extreme hydrologic alterations have been the construction of impervious surfaces such as roads and buildings in our cities and towns. However, the most widespread alteration of Minnesota hydrology has been the conversion of native prairie to farmland and the construction of the network of drainage ditches and sub-surface tile for crop production. Drainage, in agricultural areas, and water retention in urbanized areas, both have potential to significantly affect our water resources.

Glaciers left Minnesota with a young landscape that continues to be reshaped by flowing water. Glaciation left wetlands and shallow lakes, and other areas of glacial lake sediment. Percolation of water is slow through most glacial materials. In order to enable and enhance agricultural production, transportation, and economic development, the construction of drainage ditches began even before Minnesota achieved statehood. A system of ditches connects the natural stream network to previously unconnected depressions and lowered the water table near ditches. Precipitation previously stored in the depressions, and in the soil around them, was more easily conveyed to streams and rivers. Many natural streams were straightened and enlarged to increase transport capacity.

It is estimated that at the time of statehood, in 1858, the state contained over 10 million acres of wetlands that comprised approximately 19 percent of the total land area (Palmer;1915; King, 1980). These lands were viewed as breeding grounds for disease and impediments to transportation, agriculture, and development (Wilson, 2016). As codified, in 1887, the goals of Minnesota's wetland drainage policy were two-fold. First, they were to improve land productivity; secondly, they were to "remove causes of malaria". Subsequently, a series of legislative acts formed the basis of drainage laws. Costs of drainage improvements were assessed to benefited parties. The focus of drainage law was on enabling joint drainage systems across township and county boundaries. These acts formed the drainage code that currently is contained in statue, where the state counties and watershed boards act as drainage authorities.

Although multiple statutes formed the foundation for drainage law, little organized drainage took place until settlement advanced to the Red River Valley in the 1890's. The flat topography of the Red River Valley hindered drainage of fertile soils. In 1893, the Red River Drainage Commission was formed to initiate large-scale drainage systems and work began on state ditches fed by local and county ditches (Palmer, 1915; Hanson, 1987). From surface ditches, drainage evolved to incorporate tiling buy installing concrete or clay tile to remove water from isolated wet areas or by installing patterned tile to entire fields (Wilson, 2016). The tile lines fed water drained into surface ditches or natural watercourses. Activity peaked between 1900 and 1915 when it is estimated that approximately nine million acres were drained--fully 17 percent of Minnesota's total land surface (Hanson, 1987). Research on drainage at the University of Minnesota led to improvements in ditching and trenching, as ditching machines replaced hand tools.

Drainage decreased during the Dust Bowl. Between 1938 and 1945, an increase in commodity prices gave rise to an increased interest in drainage. Systems that deteriorated through disuse during the Dust Bowl were repaired and the use of drain tile became widespread. Changes in drainage law eliminated state and township drainage authorities, leaving only district courts and county boards with the ability to establish drainage systems (Laws of Minnesota, 1947). Expansion of drainage continued through the 1950's.

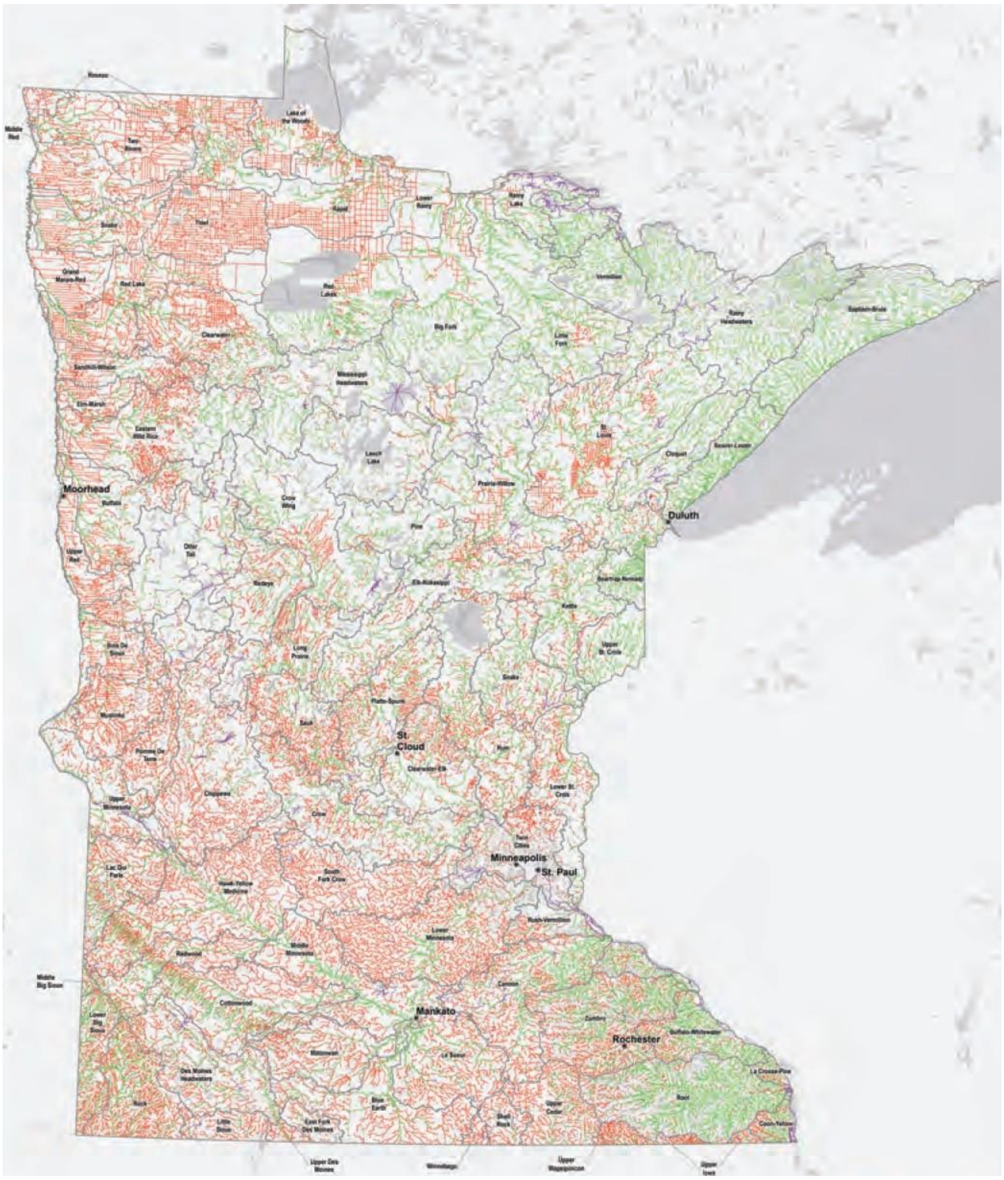
In 1955, drainage law was amended to give consideration to soil, water, forests, and habitat conservation (Laws of Minnesota, 1955a). Watershed districts created new drainage authorities (Laws of Minnesota, 1955b). In 1959, drainage authorities were granted the authority to require the spreading of spoil banks and the planning of a one-rod grass buffer strip, presumably to improve ditch bank stability (Laws of Minnesota, 1959). In the 1960s and early 1970s, conservationists began to question whether drainage was always in the public interest.

Later, a host of new state and federal environmental regulations were enacted, ranging from the federal Clean Water Act (1972) to the Minnesota Environmental Protection Act (1973). After that time, drainage was scrutinized more closely. Judicial authority to establish drainage systems was eliminated and potential ecological impacts were considered in the review of drainage projects or improvements (Laws of Minnesota, 1973). In 1976, the Legislature directed the Department of Natural Resources (DNR) Commissioner to inventory public water basins and watercourses and required the DNR and drainage authorities to examine environmental and conservation criteria before establishing drainage projects (Laws of Minnesota, 1976). Public wetlands were inventoried, and a state water bank program was established to pay landowners for not draining private wetlands.

The federal 1985 "Swamp buster Act" (Food Security Act of1985, 1985) removed eligibility for certain federal farm programs for farmers who converted wetlands to cropland. These requirements have continued in subsequent farm bills. In Minnesota, the Wetland Conservation Act (WCA) (Laws of Minnesota, 1991) regulated activities that result in the draining, filling, or excavating of wetlands, including those on agricultural land. Generally, WCA applies to non-public waters wetlands. Public water's wetlands protections are administered by the DNR.

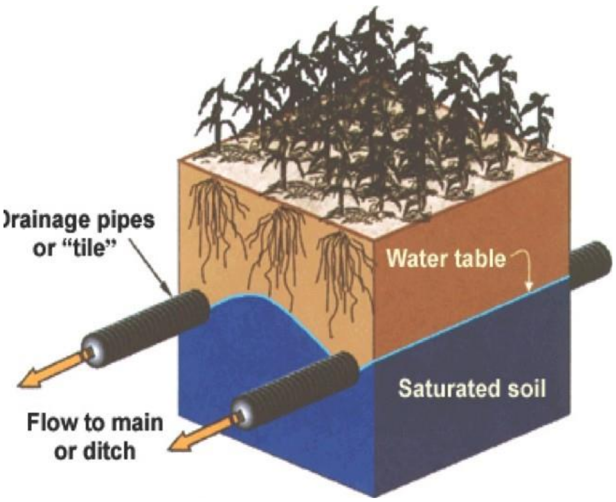
Notwithstanding the many environmental considerations in today's drainage law, no regulations specific to the practice of drain tiling have been enacted. As environmental requirements for surface drainage increased, incentives for drain tiling also increased. Drain tiling is largely a private activity conducted by individual landowners Drain tile outlets into public or private surface water bodies are not considered point sources of pollution under the Clean Water Act.

The Minnesota River basin has a particularly challenging combination of drainage issues. The Minnesota River, and tributary watersheds are perched on a glacial plain higher than the Minnesota River that flows in the deep valley created by the earlier Glacial River Warren. As a result of increasing streamflow, these tributaries are cutting back into the till plain and delivering large amounts of sediment to the Minnesota and Mississippi Rivers. Large flows in other Minnesota watersheds are also delivering sediment from streambanks, bluffs, and ravines, as well as from upland fields



Minnesota Altered Watercourse delineation, 2011, Source: Minnesota Pollution Control Agency and the University of Minnesota (Warmer colors indicate altered watersheds).

Water management in our cities and towns is similar, in many ways, to that in agricultural area, although it has developed differently. Objectives generally are to provide efficient drainage for development and to make storm water runoff more efficient. Over time, storm water management practices have been altered in urban areas by through requirements that runoff, from specific design storms, be retained on individual properties. Due to these requirements, storm-water retention basins are common in more-recently developed urban areas. The impact of these storm-water basins, on groundwater quality and quantity, is not well understood. In addition, the effects of impervious areas on groundwater recharge and quality, is poorly understood.



How drain tiles work. (Source: Minnesota Ground Water Association)

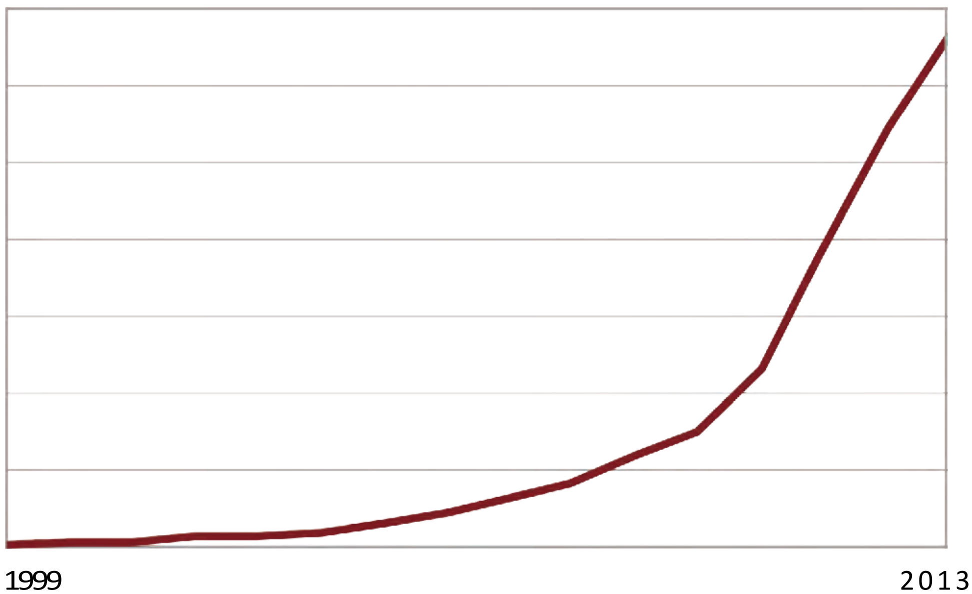
Benefits of Drainage

Poorly drained soils remain saturated or flooded after spring snowmelt, preventing efficient farm operations such as tilling and planting crops (Arman, 1963). Installation of agricultural drainage, both surface ditches and subsurface drainage, accelerate the transport of water from farm fields and results in greater crop yields (Beauchamp, 1987; Stoner and others, 1993). The most important outcome of a well-functioning subsurface drainage system is to manage soil moisture by moving water from shallow soils to surface-water features (Evans and others, 1992; Skaggs and others, 1994). Subsurface drainage lowers the water table and allow more robust root systems to develop beneath crops (Kanwar and others, 1988). By encouraging partial saturation of soil, drain tiles improve soil health by permitting biological processes that require the presence of oxygen (Moebius-Clune and others, 2017). Subsurface drainage systems also facilitate improved access and use of fields by eliminating wet surface areas (Fausey and others, 1987). By increasing root zone soil temperature and by reducing surface runoff from overflowing surface depressions, tiling provides numerous improvements to crop production. Agricultural drainage offers other benefits such as preventing crop drown out, aerating the soil profile for improved plant growth, limiting surface runoff and soil erosion, and allowing farmers better access to croplands (Fausey and others, 1987). Without agricultural drainage on much of Minnesota's croplands, it would have been difficult to realize high enough crop yields to remain economically viable.

Drainage and Information is Not Sufficient

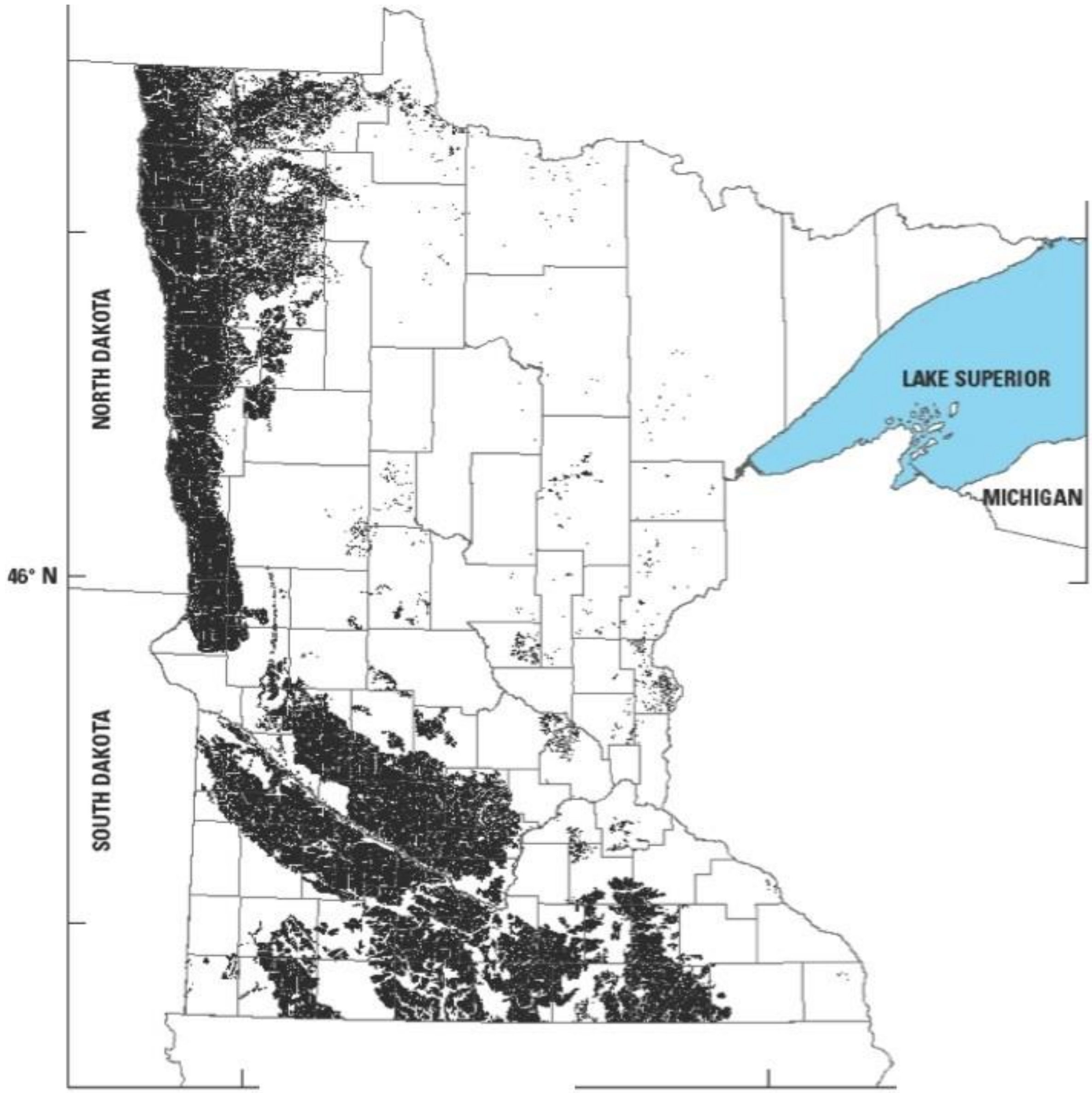
Agricultural subsurface drainage exists in large parts of southern and western Minnesota. The network of ditches for surface drainage has been augmented by installation of subsurface drainage tiles, primarily fabricated from clay or concrete. With the development of plastic pipe and efficient installation equipment, the systems have been expanded by patterned installation. However, the extent and configuration of subsurface drainage has not been fully mapped. Tile drainage is generally installed on private lands and the reporting of the installation or extent of acreage is not required by state law. There is no statewide record of subsurface field tile installation over time. Subsurface tile has been mapped in a few small watersheds, for example Seven Mile Creek Watershed).

There are eleven watershed districts that require permits for the installation of private or public drainage systems and another eleven watershed districts that require permits for the installation of drainage under certain circumstances. Although some watershed districts and soil and water conservation districts compile tile installation information within their boundaries, only the Bois de Sioux Water-shed District has records of permits required for private drain tiles. (Bbased on a paper titled: Tile Drainage Rules: A Review of Minnesota Watershed District Rules (Scott SWCD, 2017)).



Increasing trend in drainage tile permitted since 2000, as measured in miles of tile line for the Bois de Sioux Watershed, (Source Bois de Sioux Watershed District and the University of Minnesota. (Vertical lines are 2000 mile increments)

Estimates of tile drainage have also been made by the U.S. Geological Survey (Nagasaki and others (2016)). Their methodology included construction of a. model, based on the extent of cultivated land and the extent of poorly drained soils from the State Soil Geographic Data Base (STATSGO). The estimates were based on 30-meter dataset illustrating the density of tile drainage in each cell in square meters.



U.S. Geological Survey (USGS) tile drainage extent in Minnesota shown by a 30-rneter raster, based on Nagasaki and Wiecztek (2016)—Model of drainage for twelve Midwestern states.

The Minnesota DNR and MPCA also have created an approach to estimate drain time densities and have determined existing tile drainage information for eight areas. The sources of information include installation permits, aerial photographs and land-owner interviews. These methods estimate the amount of land within 50 feet of tile lines as a surrogate for effective drainage distance for tile lines. Combinations of soil (Natural Resources Conservation Service, 2005), slope (Minnesota Geospatial Information Office, 2017), and crop information (based on the 2011 U.S. Department of Agriculture (USDA) Cropland Data Layer (CDL); U.S. Department of Agriculture, 2013) were compared to the available mapped tile drainage densities.

Environmental Concerns Associated with Drainage and Water Retention

Surface Water Quantity

Drainage is a major component of change to both rural and urban landscapes. The impact of drainage has long been subject of research and debate. Because the overall purpose of drainage is to reduce or eliminate storage of excess water in soil, peak streamflow and total runoff to nearby streams are affected. However, the impacts, depending on the type of drainage used, as well as on the size of the drained watershed. Some of the considerations are as follows:

Flooding--The impact of drainage on flooding is complex. Flooding is a combined result of topography, soil type, characteristics of storms moisture conditions before the event, and the hydrology of the watershed (including drainage). Ditches generally increases flood peaks, at least in small watersheds, because they increase conveyance. In small watersheds, ditches and tile can increase flood peaks and flows because they reduce or eliminate closed basins that otherwise would store water. However, in other small watersheds, tiling tile may allow water flow through soil and reduce the downstream peak flows (Sands et al. 2012). During large rainfalls, or snowmelt events, water may not infiltrate quickly enough or the capacity of tile may be overwhelmed. Therefore, the influence of tile drainage on streamflow and flooding in large watersheds is not well understood. Subsurface tile appears to have little impact on flooding in large watersheds because large floods are dominated by surface runoff (Sands et al. 2012).

Effects of tile drainage on Water budgets--Zucker and Brown (1998) concluded that subsurface drainage reduces surface runoff by 29 to 65 percent, reduces peak flows from watersheds by 15 to 30 percent, but has little impact on the total annual flow from watersheds. A literature review by Blann et al. (2009) described the increase in total water yield as about 10 percent. Sands (2010) states that the potential for overall increases in water yield are from 5 to 10 percent. At the large watershed scale, Schottler (2013) attributed more than half of the increase in stream flow to changes in evapotranspiration brought about by increased agricultural drainage over past half century. It is generally considered that tile drainage affects water balances in several ways.

Drainage it thought to:

- **Reduce the time precipitation is stored in soil--**Only drainable water is removed by tile and ditches. The amount of plant available water (i.e., water held by soil particles against the pull of gravity) is not affected by drainage systems.
- **Change how water is stored on the land surface:** Some ditches and tile link streams to depressions that were previously not connected.
- **Reduce overland flow** (and soil erosion) when water instead moves through soil and subsurface tile.
- **Decrease evaporation** by removing areas of standing water.
- **Increase annual transpiration,** when rooting depth and productivity increase.
- **Increase the total amount of water that reaches streams** (annual yield). Models show that tiling increases the annual amount of water leaving the field.
- **Reduce, delay and extend peak flows in streams** after a precipitation or snowmelt events. Water takes longer to travel through soil to a tile system than to move overland or through ditches. This means rainfall will reach a stream later than if it only flowed overland. Soil continues to drain long after events, so elevated stream flow lasts longer than if the rain all reached the stream overland.

- **Increase watershed yield--**In areas with extensive subsurface tile drainage, lowering the water table over a large area results in a corresponding volume of water delivered by drains to downstream locations. This water would otherwise be transpired or would reach downstream locations as groundwater discharge.
- **Reduced Wetlands**--Drainage has resulted in the disappearance of much of Minnesota's natural wetlands. Prior to establishment of Minnesota statehood, wetlands accounted for more than 10 million acres in Minnesota, including prairie wetlands, peatlands, and forest wetlands that comprised approximately 19 percent of the total land area (Palmer, 1915; King, 1980). Only half of our pre-settlement wetlands remain, mostly in parts of the State that have not experienced widespread drainage such as northern Minnesota. Anderson and Craig (1984) estimated that the total acres of wetlands in Minnesota at the time of European settlement was 18.6 million acres, 8.8 million acres remained in 1984, and losses were much greater in the agricultural and urban areas than in the forested regions of the state.

Effects on Groundwater Quantity

The effects of subsurface drainage on groundwater recharge and aquifers have not been well established. Subsurface drainage intercepts infiltrating water and discharges the water to nearby surface water. However, the magnitude of the water-balance shifts from drained water to water that would have evaporated, run off, or recharged aquifers is poorly understood (Schuh, 2008). Jin and others (2004) studied water budgets for different soil types in the Red River Watershed and found that deep infiltration to groundwater accounts was a small percentage of the overall water budget. Prior to tile drainage, most water removed by drains is removed by evapotranspiration, or by natural discharge to surface waters, through lateral movement of shallow groundwater. Schuh suggested that most of the tile-drained waters in eastern North Dakota was captured from evaporation or transpiration, suggesting that tile drainage may have limited effects on groundwater recharge in those areas.

Water budgets in drained areas is difficult to quantify largely due to substantial variations in evapotranspiration rates, infiltration rates, and the general flow of groundwater. There is a lack of knowledge regarding the effect of drainage on deep infiltration that recharges aquifers. Existing recharge focuses on monitoring accessible parts of the water balance on already tiled areas. There is a lack of research focused on whether subsurface drainage increases or decreases evapotranspiration, increases or decreases the total runoff, changes water storage, or affects the recharge to underlying aquifers. These components dynamically interact and recharge to groundwater is generally considered to be a small component. Therefore, the question of whether groundwater recharge is affected is not well known.

Water retention and the effects of impervious surfaces are significant groundwater issues in urban areas. A study by the University of Minnesota addressed these issues in the Vermillion River watershed. The objective of the research was to quantify changes in groundwater recharge in an urbanizing watershed. Models were used to estimate water-budget components under stages of urban development. The study found that infiltration, evapotranspiration, and groundwater recharge all decrease as urban development increased. This study suggested that urban development significantly reduces recharge, by as much as 40 percent, due to an increase in impervious surfaces. The reduction was thought to be compounded by changes in vegetation

Effects on Water Quality

Although the effects of drainage on water quantity are complex, the impacts of drainage and water quality are more straightforward. It is generally accepted that retaining water on the land has beneficial effects for water quality, regardless of the watershed scale or size, and that these practices have downstream positive effects. Water-quality monitoring has shown that agricultural drainage, in particular the practice of subsurface drainage, provides an efficient flow path for nutrient deliver (nitrogen and soluble phosphorus) to surface water and that these flow paths are immediate when open inlets are incorporated into subsurface tile drainage systems. The negative consequences of agricultural drainage on surface water quality are well documented (Dinnes and others). Water quality impacts to streams and rivers, most frequently associated with drainage, include increased concentrations and loads of the following several constituents. These water quality concerns are as follows:

Nitrate--Results from the application of nitrate-containing fertilizers, nitrification of ammonium containing fertilizers and manure, and mineralization of organic nitrogen in manure and soil organic matter. If soil is permeable, water moves into the soil profile, and it can move out of the root zone and into tile or groundwater. Nitrate is soluble in water and not tightly bound to soil particles. Groundwater contamination with nitrate is most susceptible in areas of the state with coarse textured soils or shallow soils over porous bedrock. In Minnesota, most nitrate in surface water is delivered by subsurface tile drainage.

Phosphorus originates from fertilizers and livestock manure applied to the soil as an essential crop nutrient, and from mineralization of soil organic matter. Because phosphorus readily attaches to soil particles, it is less likely than nitrate to be transported through the soil profile. However, sufficient levels of soluble phosphorus for algae growth are being found in tile drainage water in some agricultural areas where soil phosphorus concentrations are elevated.

Pathogenic bacteria originate from wildlife and livestock manure, and malfunctioning human waste treatment systems. While not all bacteria are pathogenic, contamination of drinking water sources by pathogens is a health hazard.

Hypoxia: Agricultural basins with a high percentage of agricultural drainage have been implicated as part of the cause of the Gulf of Mexico hypoxia zone due to excessive nitrogen export (Goolsby and Battalion, 2001; Randall and Mulla, 2001

Suspended sediment is the result of erosion of soil from field surfaces, open–tile inlets, gullies, ravines, and streambanks, as well as collapse of near-channel bluffs from toe-slope erosion and other mechanisms. Drainage can increase sediment deliver to streams in direct and in indirect ways. Open-tile inlet structures can introduce sediment directly to streams during runoff events. Other forms of drainage can increase peak streamflow, resulting in field, streambank, bluff, and ravine erosion. Ravines and large gullies often supply large volumes of sediment eroded per unit of stream flow. Upland, streambank, cliff, and ravine erosion are among the largest sources of sediment to the Mississippi River. Sediment derived from upland soils can be high in phosphorus, while parent material in bluffs is often much lower.

Tile drainage is a major pathway for nitrate loss to surface water. According to the MPCA, subsurface drainage, in Minnesota, contributes 37 percent of nitrogen contamination to surface water (MPCA, 2013). In addition, tile drainage waters often bypass saturated riparian buffers next to streams (Dinnes and others, 2002). Consequently, the natural denitrification potential of these zones is lost where water bypasses buffers. An important part of the reduced denitrification potential is the shortened travel time of groundwater to surface water. Schilling and others (2015) found that mean shallow groundwater travel times were reduced with increasing intensity of tile drainage intensity in a study in Iowa.

The effect on phosphorus delivery to surface waters is assumed to be of less concern because subsurface drainage reduces overland runoff. Therefore, runoff- derived phosphorus from soils in tile-drained fields. However, some studies have found that phosphorus leaching from tile drainage can be large. King and others (2014) showed that tile drainage accounted for 47 percent of discharge and 48 percent of the dissolved phosphorus in the Upper Big Walnut Creek watershed in Ohio.

The effects of drainage on groundwater quality are not well understood. However, in urban areas, storm water retention has potential to affect groundwater quality. A study by the USGS (Tornes) focused on the impact of rain gardens on groundwater quality. Selected constituents, considered to be indicative of runoff, included suspended solids, nitrogen, phosphorus, chloride, and gross measures of dissolved constituents. Although the changes in mass transported throughout the system relative to sources were not measured, the data provide an evaluation of concentrations in components of the water system in rain gardens. When outflow was measured it contained reduced concentrations of suspended solids and most nutrient species associated with particulate material, as compared to inflow. Many of these constituents settled in the rain gardens, infiltrated into groundwater or were assimilated by plants. Site design, including capacity relative to drainage area and soil permeability, were found to be important in the efficiency of rain-garden operation. Vegetation type likely affects the infiltration capacity, nutrient uptake, and evapotranspiration of a rain garden and probably the resulting water quality. The long-term efficiency of rain gardens was not determined.

Reducing the Impacts of Drainage and Water Retention

There are many water-related concerns associated with water drainage and water retention. Rivers and streams integrate the effects of these management practices. Precipitation, vegetative cover, land management geology, soils, and landscapes characteristics all influence our rivers. In combination with other watershed characteristics, the changes we have made to natural drainage conditions magnify downstream in our rivers. These effects include excess nutrients, high sediment levels, flooding, property loss, and habitat loss. During the last half of the century, we have experienced increases in the volume of water in streams, the width of stream channels, and the amount of sediment being transported from fields, streambanks, bluffs, and ravines, primarily in southern Minnesota. The sources of sediment are primarily the result of greater stream and river flows. Increases in channel-shaping flows are related to changes in precipitation, decreases in transpiration, changes in agriculture, decreases in surface water storage due to drainage, reduced evaporation as well as changes in soil water holding capacity. To protect our rivers, farms, and wildlife, more water needs to be stored and slowly released using land and water management practices. Better water management practices will reduce erosions and sediment deliver as well as reducing nitrate-nitrogen and phosphorus. This will, in turn, improve our streams and rivers. Changes in land and water management have potential to protect and to improve downstream conditions by modifying water quality and flow. As a state we need to determine how best to apply these management practices and how to incentivize them to maintain the productivity of our agricultural and urbanized lands.

Strategies for reducing the Impacts of Drainage

Land and water management's practices have great potential to protect and to improve water quality by modifying water use and flows. The practices are most effective when then are combined in sequence in a watershed. Individually or when combined, these practices have multiple impacts that include: improved soil structure and water holding capacity, reduced channel erosion, improved water quality and in-stream habitat, and reduced flooding. Ponds and wetland restoration for water storage in agricultural drainage systems improve drainage system efficiency. They dampen peak flow, and reduce the size requirement for ponds and ditches downstream. Practices that add perennial vegetation or that diversify channel structure also reduce channel erosion and create habitat.

These practices can be characterized according to where they are located in the various landscapes and according to the effects that they have on the hydrology of a watershed. In-field crop and soil management are most appropriate in areas of intense agriculture. These practices improve watersheds by increasing transpiration, water infiltration, soil-water holding capacity as well as the resistance to soil erosion. Treatments in drained landscapes include increased drainage management coupled with water treatment and retention/detention structures, constructed wetland, ponds, irrigation reservoirs, or modified ditch channels. Treatments that are move applicable to more slopping landscapes include grassed waterway, filter strips, buffer strips, terraces and water and sediment control basins. Riparian area modification and orientation, coupled with stream channel protection are most applicable near outflows of watersheds. Because treatment methods need to be designed for local landscapes, climate and cropping systems, systems need to be developed that fit individual watersheds.

The costs for the practices, described below, differ considerably with size, location and other factors:

Soil Management: Enhancing the ability of the soil to infiltrate and store precipitation. Soil and crop management in agricultural fields affects infiltration rates and water holding capacity through changes to soil structure and soil organic matter. In-field crop and soil management is appropriate in areas of intense agriculture. They improve watersheds by increasing transpiration, water infiltration, soil-water holding capacity as well as the resistance to soil erosion.
Increased Transpiration: Manage the amount and distribution of crop transpiration throughout the year. Transpiration is the largest user of precipitation water, and its timing relative to rainfall distribution has a great influence on how much surplus water will move off the land.
Managing Overland Flow: Manage overland flow with crop residue, contour farming, and vegetated flow pathways like waterways and filter strips that slow, filter, and partially infiltrate surface runoff.
Subsurface Drainage: Managing subsurface drainage flow by sizing, depth, and spacing of drainage pipe to control rates of drainage water leaving the field. Control structures can also be installed in the drainage system to allow temporary water storage for later crop use or timed release.
Water Storage: Increasing water storage, including natural storage in wetlands and other depressions, and artificial storage with constructed wetlands, terraces, water and sediment control basins, down-sized culvert retention, weirs, and large detention basins.

Streambank Protection and Riparian Area Restoration: Establish measures to protect channels and restore riparian areas.
Green cover crops and Agricultural Alternatives to corn and soybean rotations have great potential to slow the delivery of water, sediment and nutrients to our ground and surface water. The challenge is in finding crops that can compete with corn and soybeans economically.
Conservation Drainage Practices include retention structures, shallow drainage, woodchip bioreactors, saturated buffers, gravel inlets, two-stage ditch design, constructed wetland, ponds, irrigation reservoirs, or modified ditch channels, and various kinds of storage basins. These practices are most effective when then are combined is sequences in a watershed. Individually or when combined, these they have multiple impacts that could include improved soil structure and water holding capacity, reduced channel erosion, improved water quality and in-stream habitat, and reduced flooding. Treatments applicable to slopping landscapes include grassed waterway, fitter strips buffer strips, terraces and water and sediment control basins.
Pond and wetland restoration improve drainage system efficiency. They dampen peak flow, and reduce the size requirement for ponds and ditches downstream. Urban storm water retention facilities reduce Peak flows. Peak flows drive streambank erosion. Storage is especially effective in small watersheds that have a high sediment yield. However, the impact of stored waters in urban areas is not well established. We do not fully understand if groundwater recharge is increasing or decreasing. We also do not understand time impacts we are having on groundwater quality.

Managing Drainage by Province: The Minnesota Groundwater Association has proposed adoption of drainage provinces to aid in understanding and managing regional differences in subsurface drainage and its effect on groundwater resources. Built upon the concept of groundwater provinces, three distinct drainage provinces consist of: (1) the Southeastern Province; (2) the Southcentral Province; and, (3) the Western Province. The distinct geology and the soils in each of these regions have implications for each region's subsurface drainage density and the potential implications for groundwater.

Buffers: Buffers along streams, rivers and ditches have good potential to slow water, sediment and nutrient delivery as well as increasing biological habitat. The Legislature directed the Board of Water and Soil Resources (BWSR) to coordinate the Drainage Work Group to evaluate and develop recommendations to help Minnesota drainage authorities accelerate the acquisition and establishment of buffer strips and alternative practices adjacent to public drainage ditches and associated compensation of landowners. The impetus for this action was the 2015 Buffer Law which required landowners to establish buffer strips, or alternative practices, along all public drainage ditches. Recommendations were developed by the Drainage Work Group with BWSR staff support. The Advisory Committee formulated actions for statutory, funding, and administrative policy changes, and outreach. The report was approved by the Drainage Work Group, accepted by the BWSR Board, and transmitted to the Legislative Policy Committees. The recommendations were categorized according to the type of action required and grouped according to the potential for the recommended actions to accelerate the acquisition and establishment of drainage system buffer strips, alternative practices and landowner compensation. The following recommendations should be given consideration for adoption and the process undertaken by the Drainage Working Group should be consider for other water management strategies outlined in this report. The recommendations of the Drainage Working Group are as follows:

- Amend Section 103E.021 to allow, with landowner consent, a drainage authority to seed and establish ditch buffer strips in advance of drainage law proceedings to determine damages and acquire a permanent easement.

- Make a statutory change in Chapter 103E to allow drainage authorities to acquire and establish buffer strips with apportionment of the costs on a per acre basis equally among all lands in the contributing watershed of the drainage system.
- Clarify Section 103E.021, Subd. 6 to expressly state that upon findings and an order, the drainage authority is vested with jurisdiction over property rights acquired for 16.5 ft. ditch buffer strips.
- Revise Section 103E.351 Redetermination of Benefits and Damages to enable 26 percent of benefited landowners, or owners of 26 percent of the benefitted lands, to petition a redetermination of benefits in order to update outdated benefited area(s) and benefits on record and more equitably apportion drainage system costs.
- Create an exemption for landowners under Section 103F.48 for drainage systems, which do not have a specific DNR shore land classification, where a buffer has been acquired, established and enforced under Chapter 103E.
- Increase and extend funding for the Buffer Cost Share program based on an estimate of need.
- Modify the Buffer Cost-Share program to allow drainage authorities to access funds on behalf of the drainage system, in coordination with applicable landowners and Soil and Water Conservation
- Districts, to establish buffer strips, but not to acquire land rights, along Chapter 103E ditches in accordance with Section 103F.48.
- Provide priority consideration for eligible external sources of funding to drainage authorities based on progress toward acquisition and establishment of buffer strips under Chapter 103E.
- Modify Section 103E.305 to clearly enable county appraisers or deputy appraisers to serve as viewers where no conflict of interest exists.
- Clarify Section 103E.071 County Attorney, to make it clear that drainage authorities, including counties, may hire outside legal counsel per Section 388.09, Subd. 1.
- Provide funding from outside the drainage system to cover the water quality purposes for acquiring and establishing Chapter 103E ditch buffer strips.
- Investigate a potential funding source and sponsor to complete a viewers’ guidance manual.
- Develop a lower cost method to do redeterminations of benefits or funding to cover the costs of redeterminations of benefits.
- For a ditch system that doesn’t have adequate cash flow capability, modify an existing or create a new loan program for buffer strip acquisition and establishment.
- Drainage authorities should consider inventorying alternative practices, such as side inlets and other infrastructure (e.g. tile outlets), that may affect the integrity and management of the system.
- Develop a coordinated outreach effort landowners, drainage authorities and their advisors, involving AMC and MAWD, with assistance from BWSR and other partners, to inform them of the drainage law provisions and potential external financial assistance for acquisition and establishment of drainage system buffer strips. Suggested elements to include:

Recommendations

There are many water-related concerns associated with water drainage and water retention. Rivers and streams integrate the effects of these management practices. Precipitation, vegetative cover, land management geology, soils, and landscapes characteristics all influence our rivers. In combination with other watershed characteristics, the effects of changes we have made to natural drainage conditions magnify downstream in our rivers. These effects include excess nutrients, high sediment levels, flooding, property loss, and habitat loss. During the last half of the century, we have experienced increases in the volume of water in streams, the width of stream channels, and the amount of sediment being transported from fields, streambanks, bluffs, and ravines, primarily in southern Minnesota. The sources of sediment are primarily the result of greater stream and river flows. Increases in channel-shaping flows are related to changes in precipitation, decreases in transpiration, changes in agriculture, decreases in surface water storage due to drainage, reduced evaporation as well as changes in soil water holding capacity. To protect our rivers, farms, and wildlife, more water needs to be stored and slowly released using land and water-management practices. Better water management can reduce erosion and sediment deliver as well as reducing nitrate-nitrogen and phosphorus. This will, in turn, improve our streams and rivers. Changes in land and water management have potential to protect and to improve downstream conditions by modifying water quality and flow. As a state we need to determine how best to apply these management practices and how to incentivize them to maintain the productivity of our agricultural and urbanized lands.

Draft Recommendations: Some critical knowledge gaps exist in our understanding and management of water management at watershed scales:

1. ***The overall extent of drainage is needed. Direct estimates of the extent of subsurface drainage do not exist in Minnesota. However, several indirect methods could be utilized to estimate the extent of surface drainage statewide.***
2. ***Fund a cost/benefit/return on investment analysis of conservation drainage-management practices***
3. ***Create an organizational structure, similar to the Drainage Working Group, that encompasses all conservation- management practices***
4. ***Quantify the extent and distribution of open-tile inlet structures across the state and create incentives to replace them with alternatives***
5. ***Effects of drainage on underlying aquifers is unknown. A basic understanding of the impact on unconfined, and confined, aquifers is necessary to quantify the effects (quantity and quality) of agricultural drainage on shallow groundwater. This should include an evaluation of the effects on groundwater recharge.***
6. ***The effects of urban storm-water retention systems and rain gardens needs to be evaluated with respect to the quantity and quality of ground water***
7. ***An improved understanding of historical water-balance shifts from pre- to post-drainage periods is needed to understand long-term implications on groundwater recharge. More direct field-scale studies and modeling studies are needed to characterize water budgets for fields with subsurface drainage.***
8. ***Existing tools and systems need to be applied and used to identify the appropriate best management practices at landscape and watershed scales***

9. ***Utilize the one-watershed/one-plan process to locate and to implement best- management practices, within watersheds, at appropriate places and scales***
10. ***Evaluate the effects of drainage on by wetland systems***
11. ***Design programs to quantify potential problems of emerging contaminants in urban storm water retention basins***
12. ***Promote the role and importance of the relationship between healthy soil and healthy water. Establish programs to improve soil health, aimed at increasing agricultural productivity and water retention***
13. ***Support the recommendation of the Drainage Working Group***
14. ***Expand the responsibilities of the Drainage Working Group to include all drainage and water retention activities, rural and urban***
15. ***Quantity and map areas of deep aquifer recharge as areas that need to be protected from chemicals introduced as the result of drainage and water retention activities***
16. ***Encourage programs to maintain and upgrade rural ditches and culverts that reduce erosion and encourage fish passage***