BASIN TECHNICAL AND SCIENTIFIC ADVISORY COMMITTEE

(BTSAC)

Water Management Options for Subsurface Drainage

Briefing Paper #2

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INTRODUCTION

The Red River Retention Authority (RRRA) formed the Basin Technical and Scientific Advisory Committee (BTSAC) consisting of accredited hydrologists, engineers, and natural resources scientists (not policy makers) to provide sound hydrologic, scientific, and technical advice for the purpose of managing agricultural drainage development in the Red River Basin. The role of the BTSAC is to utilize science and best professional judgment to address technical issues and questions posed by officials in the Red River Basin who are responsible for managing water resources.

The BTSAC is evaluating the hydrologic effects from extensive and widespread tile drainage within the Red River Basin and developing recommendations for local officials to manage agricultural drainage systems with the goal of maximizing benefits and minimizing potential downstream impacts. As a first step, the BTSAC reviewed numerous research publications and other subsurface drainage technical information in order to articulate a series of conclusions for the RRRA membership. The BTSAC also developed a research plan and hydrologic modeling effort to better understand the impacts of subsurface drainage at the watershed scale (BTSAC, 2011).

The installation of subsurface drainage in the Red River Basin has greatly increased in recent years due to the region's current wet period and cropping patterns, as well as the current high commodity prices. Tiling of Red River Basin fields with cropping problems due to excess water will be commonplace into the future if the current wet period continues. Water managers from North Dakota and Minnesota currently have a limited window of opportunity to implement a standardized and effective risk management strategy for subsurface drainage systems.

This second briefing paper outlines a strategy for permitting or otherwise managing subsurface drainage systems in the Red River Basin. The recommendations are based on the current state of knowledge and best professional judgment of BTSAC members.

The audience for this paper is the RRRA and its member watershed and water resources districts.

CURRENT SUBSURFACE DRAINAGE PERMITTING

Current drainage permitting requirements vary greatly across the Red River Basin in the United States. North Dakota and Minnesota each have unique public water resource regulatory strategies and authorities established in state law.

North Dakota

The North Dakota State Engineer (State Water Commission) and local Water Resources Districts and Joint Water Resources Districts are responsible for managing the state's water resources (ND Century Code, 2011). Prior to 2011, the State Engineer would first review subsurface drainage permit applications to determine if the project had statewide or inter-district significance, then send the permit application to the respective Water Resource District for final review and decision.

In 2011, North Dakota passed legislation aimed at streamlining the subsurface drainage system permitting process by bypassing the State Engineer's application process and the determination of statewide or inter-district significance.

The 2011 legislation allows any subsurface drainage project of less than 80 acres to proceed without a permit. The legislation also eased the regulatory burden on all larger subsurface drainage projects. Individuals wishing to install subsurface drainage projects that comprise an area of greater than 80 acres must apply to the local Water Resource District for a permit, but the District may not deny the permit unless the District determines the application is of statewide significance or the proposed drainage will flood or adversely affect downstream landowners within one mile of the proposed subsurface drainage project.

Minnesota

Watershed Districts, which cover most of the Red River Basin in Minnesota, have the authority to permit all surface and subsurface agricultural drainage activities through state statutes (Minnesota Statutes 103D, 2011). Watershed Districts in the Red River Basin have independently developed rules for permitting. One Watershed District requires a permit for all private field drainage activity and regulates subsurface and surface drainage activity using a variety of management tools including maximum permissible drainage coefficients (tile capacity determined by soil type, tile size, spacing, and depth; surface drainage capacity determined by applicable methods), culvert sizing, and operating plans (C. Anderson, personal communication). Some Watershed Districts require subsurface drainage permit applications, but no criteria or regulations are applied other than a request for information such as location and system design which is used to inform downstream landowners and/or the outlet ditch authority and determine if there are any concerns or opposition to the proposed project. Another Watershed District recently decided to limit the drainage coefficient for subsurface drainage permits to a ¼ inch per day (D. Money, personal communication). Other Watershed Districts require no information or permit application for any private drainage activities (M. Jesme, personal communication).

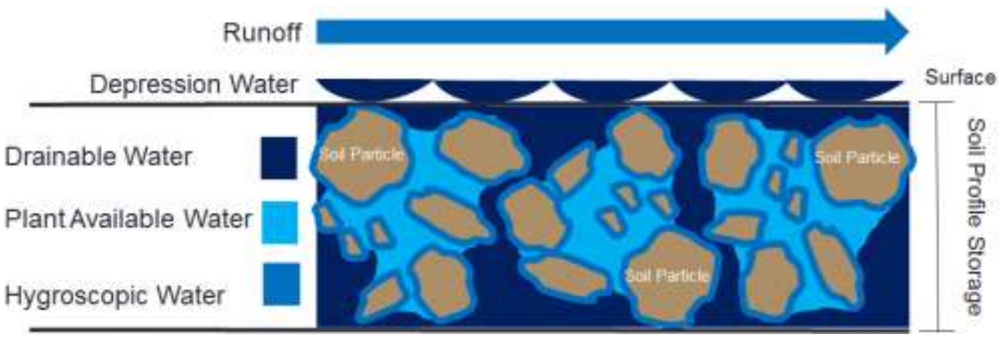
HYDROLOGIC EFFECTS OF SUBSURFACE DRAINAGE ON DOWNSTREAM FLOW

Subsurface drainage is one portion of the overall agricultural and natural drainage system that may affect flood flows and duration in a watershed. Adding subsurface drainage does not, under most pre-flood scenarios, increase the overall capacity of the soil to store water; rather, it changes how a portion of water in the soil and on the surface is stored and released over time. Determining how subsurface drainage can affect downstream flows requires an understanding of the dynamics and sources of water contributing to the overall hydrologic system and the range of conditions that exist prior to - and during - a flood event.

Components of Surface and Soil Water Fractions

Surface water can exist in depressions and as surface runoff. Precipitation may collect in small to large surface depressions that are hydraulically disconnected from receiving waterways unless overtopped by continuous rainfall or snowmelt. Runoff water moves across the land surface via sheet, rills, and/or ditches to receiving waterways. Soil profile water may be described in three primary categories: (1) the hygroscopic fraction (under the driest soil-water conditions, the water bound tightly to soil particles); (2) the plant-available fraction (water occurring between permanent wilting point and field capacity) and; (3) the drainable fraction (Sands, 2001). Drainable soil water (also known as gravitational water) can move through the larger soil pores as a result of gravitational forces. Soil types differ in terms of the relative size of these fractions (e.g. finer-textured soils can store more plant available water). At any given time, water in the soil profile may exist in one, two, or all three of the fractions (Figure 1).

Figure 1. Soil Profile and Surface Water Fractions.



Subsurface Drainage Effects on Surface Depression Storage and Drainable Soil Water Fractions

<u>In the absence of subsurface drains</u>, soil profile and surface depression water can evaporate; transpire through vegetation, or infiltrate deeper into the ground. Water in surface depressions and in the drainable soil profile water fraction is considered long-term (**retention**) storage because there is no drainage pathway allowing this water to contribute to downstream flows. The potential for this retention storage to affect flood events depends on the conditions that precede the flood event (**antecedent conditions**) and what fraction of the retention storage is available (not already full).

<u>When subsurface drains are present</u>, the drainable water fraction of the soil profile water is converted to short-term (**detention**) storage by removing it from the system over a period of hours, days, or weeks, depending on a number of variables including drain tile size, depth and spacing, soil type, outlet size/condition, and whether or not the rainfall or snowmelt continues to occur. When drainable water is removed from the soil profile, infiltration can then occur due to available soil pore space allowing water that would otherwise be stored in the surface depressions to infiltrate and have a direct pathway to downstream flow (via the subsurface drains). Converting the drainable soil water fraction and surface depression water to detention storage may, under some conditions, exacerbate flood flows if it is released during a flood event.

At the field scale, converting soil profile and surface depression storage from retention to detention appears to be beneficial (i.e., reduce peaks, delay runoff, improve field access during planting and harvesting, and increased agricultural productivity). At the watershed and basin scale, converting soil profile and surface depression storage from retention to detention may have either beneficial or detrimental effects on flood flows depending on the location of the field in the watershed and other factors.

Hydrologic Considerations

Available literature and modeling (BTSAC, 2011) indicate that the installation of subsurface drainage systems can result in three *field-scale* hydrologic phenomena: (1) decreased peak discharge, (2) delayed discharge, and (3) increased water yield (primarily spring and fall - when crops are not growing).

The hydrology of an agricultural field is affected by the occurrence and timing of precipitation (rainfall and snowmelt), surface and subsurface water storage, surface runoff, infiltration, evaporation/transpiration (ET), and seepage (both lateral and vertical). Each of these processes is influenced by soil type, crop type and growth stage, surface topography and agronomic factors. The hydrology of a watershed or river basin is more complex than that of a field, due to the effects of scale, gradient, and heterogeneity. Predicting or ascertaining the downstream, large-scale hydrologic impacts of subsurface drainage or other field-scale water management practices is difficult because these myriad factors cause hydrologic events to unfold in many different ways. Nevertheless, it is possible to describe scenarios where certain hydrologic processes may be prominent (or dominant), in order to better understand the system as a whole.

Total water yield from a field is the sum of surface runoff and subsurface drainage flow (if drains are present). Both of these flow contributions can be relatively fast, with surface runoff occurring within minutes to hours of a precipitation event, and subsurface drainage occurring within hours to days of an event. The hydrology of any particular event depends on the intensity and duration of rainfall/snowmelt and the antecedent condition of soil water and surface depression storage.

Frost can also effect the infiltration of soil profile and surface depression water. If frost is present and impervious during an early spring thaw, all snowmelt or rainwater will directly run off the surface regardless of whether or not subsurface drains are present. If frost is porous or non-existent during an early spring flood event, uncontrolled subsurface drainage can convey water from the soil profile and surface depressions to receiving waterways which can potentially increase downstream peak and duration. This no frost or porous frost condition occurred in some recent winters when tile drains continued to flow into the late fall and winter.

Scenarios

There are scenarios in which subsurface drainage may reduce flood flows. Subsurface drainage reduces soil profile moisture content which enhances plant root penetration and proliferation and evapotranspiration. Higher rates of evapotranspiration can increase storage potential in the plant-available soil-moisture range between field capacity and the wilting point (the minimal point of soil moisture the plant requires not to wilt). The increased soil profile retention storage created by higher rates of evapotranspiration during the growing season would be most effective in helping to minimize summer floods. However; when relatively dry conditions follow the growing season, the enhanced soil profile storage potential may carry over and be available to decrease spring flood potential as the water table is often below the tile lines due to upward movement of moisture from crop transpiration. Decreasing the soil profile moisture content and lowering the water table can also increase the porosity of frost and enhance the rate of infiltration and frost removal during the spring melt. Additionally, at watershed locations which contribute water to the peak or descending limb of the mainstem flood hydrograph, the delayed and decreased peak from fields with subsurface drainage may also be beneficial in reducing peak flows.

There are also scenarios in which subsurface drainage may increase flood flows. Wet fall conditions can result in the soil profile remaining saturated to some level prior to a spring flood event. If no subsurface drainage is present, surface depression water and the drainable water in the soil profile would not have a pathway to receiving waterways and therefore not contribute to flood flows. In addition, unless the soil profile is saturated to land surface there will be some porosity available for water storage during the spring melt. Unmanaged subsurface drainage will drain the water table to the level of the tile and the soil moisture profile relative to land surface will be determined by the capillary influence of the water table. Under these conditions (unless the drains are closed) there will be no porosity available for soil storage of infiltrating surface water, and all surface depression water that would have been stored without the drains will infiltrate downward through the soil profile as mobile water and add to the hydrologic event.

CONCLUSIONS

The issue of concern for water managers is not that tile drainage will always and everywhere have a negative effect on flooding. Rather it is that within the many and complex potential scenarios for the interactions between climate, soils, crops, hydrology and management, there are scenarios that must be considered when evaluating risk.

Available research and modeling indicate there are scenarios, wherein uncontrolled or improperly managed subsurface drainage systems convey drainable soil profile and surface depression water (water that is normally retained in fields without subsurface drainage systems) to receiving waterways from fields during spring flood periods. Although field-scale agronomic and hydrologic phenomena from subsurface drainage are fairly well documented, there is currently inadequate understanding of the larger-scale hydrologic effects to draw definitive conclusions for all antecedent and snowmelt conditions. Where scientific knowledge is limited, BTSAC focused on defining the limits of their collective understanding (acknowledging gaps) to facilitate future research goals, define known risk, and formulate appropriate policy options managers can implement to compensate for that risk.

BTSAC has concluded that situations exist where adding uncontrolled subsurface drainage to areas of the landscape has the potential to increase flooding. This risk must be considered and evaluated in water management decision making. The BTSAC could not quantify the probabilities of scenarios where tile may contribute water to flood flows nor the effect of frost on the starting date of the tile flowing in the spring.

BTSAC has also concluded that the inclusion and appropriate operation of control structures on existing and proposed subsurface drainage systems can maximize water storage potential and potentially reduce flood flows. An important benefit of appropriately managed subsurface drainage is that it could provide a valuable tool to maximize soil storage and minimize flooding. One of the potentially negative effects of unmanaged subsurface drainage is the possibility of conveying additional soil profile and surface depression water to receiving waterways during floods. Assuming conditions allow, subsurface drains with control structures could be managed to remove surface and soil profile drainable water in late fall, winter, or early spring and then be closed to detain the water during the critical spring flood periods.

The long-term climate history in the Red River Basin has also shown a tendency for extended wet and dry periods. During dry periods, unmanaged subsurface drains may remove valuable subsoil water that could benefit crops, while managed subsurface drains would have the capability to restore optimal water retention during dry periods. There is also ongoing research indicating that sub-irrigation might be possible in some areas, if control structures were part of the water management system.

SUBSURFACE DRAINAGE MANAGEMENT OPTIONS

BTSAC formulated the following management options to reasonably account for the possible field scale effects (delayed discharge, decreased local peak, and increased water volume) from subsurface drainage systems and the uncertainty/risk associated with the rapidly increasing trend of subsurface drainage installation in the Red River Basin.

There are many complex water management policy issues involved with implementing the options including the balance of public and private cost, risk, benefit, and equity. The BTSAC, in its current composition and time constraints, is not prepared to address policy issues. There are also specific issues on the details of comprehensive drainage management (surface as well as subsurface) and coordinated efforts within the Red River Basin and between the States that need more study and cannot be fully addressed in this paper.

The window of time for consideration and promotion of the managed drainage options may be limited due to the expense and difficulty of retrofitting existing subsurface drainage installation with effective control systems. The subsurface drainage management options should be viewed as a "tool box" of measures that are intended to provide an initial framework for water resource managers to consider until a more detailed and comprehensive subsurface drainage permitting/management model is developed by the RRRA and its member districts.

Controlled Subsurface Drainage (Preferred)

The potential adverse impacts of subsurface drainage, related to both timing and volume increase, can be offset by shutting down subsurface drainage during flood periods. In very flat fields, this can be accomplished by including a control device (which can include control boxes, shut off valves, and lift stations that can be shut off) near the tile outlet. In sloping fields, the subsurface drainage system needs to be designed to control the outflow from zones of relatively equal elevation within the field, including control devices at about each one foot contour interval. The operation for these control devices is needed to achieve both crop production and watershed flood damage reduction objectives. However, the operating plans must include a provision requiring that drain flows be shut down whenever their release would be expected to contribute to downstream flooding.

Water Storage Trading (Preferred)

Controlled subsurface drainage systems can provide valuable flood reduction benefits by removing drainable soil profile and surface depression water in advance of a flood event and temporarily storing water during a flood event. A water storage trading system could be established to provide incentives to use managed/controlled subsurface drainage systems to provide water storage during flood events that would not be available without managed drainage. Credit can be given if the operating plan includes a provision that the controlled drains must be fully open before freeze up and kept open all winter until shut down prior to flood conditions. *Additional* credit could be given if the operating plan includes a provision that the drains must remain open at all times when flood conditions do not require closure. However, operating controlled subsurface drainage only for flood damage reduction would conflict with operating it for reduced nutrient transport and saving drainable soil profile water for crop use during the growing season. The credits could be purchased by other landowners in the watershed who are unable or unwilling to install controls on their subsurface drainage systems. The credits could also be purchased by municipalities and others as part of their flood mitigation plans.

The concept of water storage trading credits requires more development, but the revenue generated by purchasing credits could help offset the cost of retrofitting existing subsurface drainage systems or installing controls on proposed subsurface drainage projects. The water storage trading program could also provide financial incentives to expand the network of controlled subsurface drainage systems, eventually leading to a watershed-wide system of managed control structures.

Subsurface Drainage Coefficients

There is increased risk associated with high capacity uncontrolled subsurface drainage systems in certain areas of the watershed. Because field conditions, agronomic needs, and soils vary across the landscape, lower drainage coefficients (DC – design capacity to remove a given amount of water from a field over a 24 hour period) could be presented to the producer as an alternative to other control methods in areas of the watershed. While a lower DC may be a cost effective option for some, it may not sufficiently minimize economic risk for others who may find the control and managed drainage structures to be more reasonable.

Watershed Management Options

The MN Flood Damage Reduction Work Group's Technical and Scientific Advisory Committee (TSAC) analyzed the effectiveness of a number of comprehensive water management strategies to determine their effectiveness in reducing peak flows at watershed scales (TSAC, 2011). Comprehensive watershed management strategies have the potential to address larger scale watershed flow reduction goals and offset potential cumulative flow increases from unmanaged subsurface drains.

On or Off-Site Storage

Mitigating the risk of increased flood damages can be achieved through the construction (and operation) of small and large floodwater storage projects. Smaller on-site mitigation projects may include wetland restoration (e.g. Natural Resources Conservation Service Wetland Reserve Program) providing design measures to allow appropriate drawdown of water during non-flood periods in order for the storage to be available during the flood event (Eppic et al. 1998). Construction of off-site storage may be more practical where field location or topography is not conducive to on-site mitigation. Larger flood damage reduction projects such as the North Ottawa Project and Maple River Dam have been constructed at locations in the Red River Basin. These projects have been effective in reducing downstream flood damages.

Culvert Sizing

Culvert sizing is another strategy for on or offsite water storage. Culvert sizing increases temporary storage during flood events through short term/on-channel storage on adjacent lands upstream from road crossings. Using modeling of a hypothetical watershed, Solstad et al. (2007) provided detailed culvert sizing guidelines for flood damage reductions and developed a series culvert sizing guiding principles:

- Risk to highways should not exceed current standards in terms of safety and maintenance
- Risk to developed properties upstream of road crossings should not exceed accepted Standards

- Benefits of drainage should be equitable throughout the drainage system
- The drainage system should detain water in excess of downstream channel capacity, to the extent practical
- The responsibility to temporarily store excess water on cropland should be uniformly distributed throughout the drainage system, to the extent practical
- Detention of water on cropland for most rainfall events should be no longer than 24 to 48 hours to avoid crop damage
- The recommended design methodology should be easy to apply, yet comprehensive enough to provide safe roads and an equitable and effective drainage system; and
- Guidance should provide an incremental approach to implement culvert sizing one site at a time, in addition to a subwatershed approach, and provide for transitioning from the incremental approach to the subwatershed approach over time.

STRATEGY

The application of the options should be based on the "early, middle and late water" concept while also considering the known risk and potential benefits from subsurface drainage systems. The concept of "early", "middle", and "late" water was advanced by the Technical and Scientific Advisory Committee (TSAC) as part of the Minnesota Flood Mitigation Agreement (FDRWG, 1998).

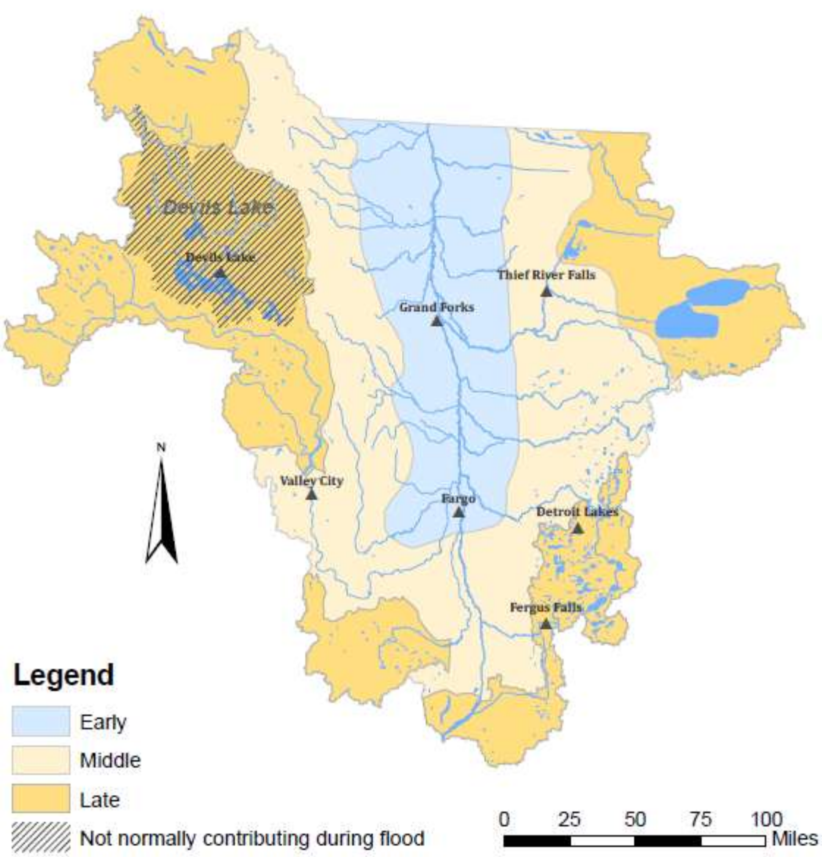
TSAC used evaluations of historic and recent flood hydrographs and computed runoff travel times to delineate early, middle, and late runoff areas in the Minnesota portion of the Red River Basin relative to the mainstem of the Red River. In general, flow contributions from areas closest to the Red River (early or furthest downstream on a given tributary) tend to arrive ahead of the mainstem peak. Flow contributions from tributary areas furthest upstream (late) tend to arrive after the mainstem peak. Tributary area flows in between (middle) tend to coincide with the mainstem peak flow and therefore, have the greatest impact on mainstem peak flow (Anderson and Kean, 2004).

As part of their efforts to develop long term flood solutions, the Red River Basin Commission (2011) developed approximate boundaries of the early, middle, and late water areas for the entire Red River Basin. The lines delineating the early, middle, and late regions are not exact;

therefore, the approximate map regions should be used in conjunction with local knowledge of runoff timing (Figure 2).

For most Red River Basin soils, subsurface drainage tends to 1) decrease peak discharge, 2) delay peak discharge, and 3) increase water yield (total volume) thereby extending the flow peak and duration of runoff from a given *field* hydrograph. The increased total water yield from a field will have the greatest potential for increasing mainstem peak flow and duration in the early and middle contributing areas of the watershed. Delaying the release of water in the early areas will increase the potential for higher mainstem peak flows, while delaying the release of water in the middle and late areas will tend to decrease mainstem peak flows or no impact.

Figure 2. Red River Basin: Early, Middle, and Late Water Regions.



Concerns for the larger watershed impacts is the risk associated with the greater water volume from a given field by converting the soil and surface depression water from retention to detention storage and the delayed discharge from a given field. Table 1 presents a summary of the expected positive and negative effects of (non-managed) subsurface drainage on downstream flooding during a high risk flood scenario, based on the location of the tile drainage in early, middle, or late areas relative to the mainstem of the Red River. However these effects will be different when the preferred option – field control structure - is implemented because field discharge from subsurface drainage systems will be managed.

Table 1. Unmanaged Subsurface Drainage Downstream Effects (Early, Middle, and Later Water).

Effect	**Early Water**	**Middle Water**	**Late Water**
Increased Volume	(-)	(- -)	(-)
Delayed Peak	(-)	(- or +)	(+)
Decreased Peak	(+)	(+ +)	(+)

Note: (+) Beneficial and (+ +) more beneficial to mainstem flood reduction; (-) Detrimental and (- -) more detrimental to mainstem flooding

The local drainage authority and landowners can implement one or more of the options to reduce the risk and optimize the benefits from subsurface drainage systems. The local authority can implement the options based on the needs of the landowner seeking a subsurface drainage permit, the location of the field (early, middle, or late water), and other local factors deemed important (Table 2).

Table 2. Options, Watershed Location, and Peak Flow Impact Potential.

Options	Early Water	Middle Water	Late Water
Preferred - Field Outlet Control	Reduce	Reduce	Reduce
Preferred - Control structure mitigation bank	Reduce	Reduce	Reduce
Subsurface Drainage Coefficient Limits	Increase	Reduce	Reduce
Off/On-site Storage Option	Depends*	Reduce	Reduce
Culvert Sizing	Increase	Reduce	Reduce

*Factors to consider include the type (e.g. gated vs. un-gated) and duration of storage.

Although this paper focuses on subsurface drainage, it should be noted that surface drainage system capacity and runoff timing are very important in regard to the effects of runoff on flood peaks.

NEXT STEPS

The BTSAC is currently utilizing a Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model developed by the US Army Corps of Engineers to evaluate the cumulative impacts of tile flow at the subwatershed scale (≈ 25 square miles). GSSHA is a state-of-the art physically-based hydrologic model that includes detailed routines to evaluate: 1) the movement of water through the soil column, 2) surface runoff resulting from rainfall events that exceed the infiltration capacity and runoff during saturated soil conditions, 3) dynamic channel and culvert flow, 4) lateral movement of the shallow groundwater table, and 5) tile flow (Drainage Coefficients) and cumulative impacts (USACE, 2012). If adverse cumulative impacts are determined, the model will then be used to evaluate the watershed management options and Early, Middle, Late Water concepts to offset subsurface drainage impacts. This modeling effort is expected to be completed within six to eight months.

BTSAC is also awaiting results from ongoing University of Minnesota, Minnesota Department of Agriculture, and North Dakota State University Extension Services research at selected subsurface drainage fields in the Red River Basin. Data generated from these efforts will be used to improve the GSSHA model and; if warranted, refine or add to the recommendations and options for managing water resources in the Red River Basin.

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