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Watershed Monitoring Benefits Private Lands and Public Water Supplies

EWF-012

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Cover photo by Blake E. Alldredge, Texas A&M AgriLife Extension Service

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Introduction

Texas boasts almost 172 million acres of land that drains into over 191,000 miles of creeks, rivers, and lakes. The Texas landscape is undergoing rapid changes with increasing rates of urbanization, fragmentation, oil and gas development, invasion by exotic species, and conversion from one land use to another. Understanding how these changing land uses affect the state's water resources is of paramount importance for ensuring clean, abundant water for Texas.

The best way to assure water quality in Texas is by the 'Watershed Approach' that provides a flexible framework to manage water quality in specific watersheds. A watershed is the land area that drains via runoff on the surface or through groundwater to a single point, such as a creek, river, lake, aquifer or ocean. It is important to recognize that all land is part of a watershed, and everyone lives in a watershed. Private land ownership accounts for 84% of the state's entire land area, and good land stewardship improves agricultural sustainability and wildlife habitat.

In response to water quality issues across the country, the United States Congress passed the Clean Water Act (CWA) in 1972. The CWA established the framework for regulations and set the U.S. Environmental Protection Agency (EPA) as the nationwide administrator of the CWA. The EPA works with natural resource agencies in each state, which are charged with establishing and maintaining water quality standards for waterbodies in their state.

Point source pollution is pollution originating from a clearly defined, fixed point. Whereas *nonpoint source pollution* does not originate from a single point but from many different places across the landscape. In Texas, 92% of the waterbodies are affected by nonpoint sources of pollution.

In Texas, the primary agencies working to improve waterbodies are the Texas Commission on Environmental Quality (TCEQ) and the Texas State Soil and Water Conservation Board (TSSWCB). TCEQ is charged with managing *point source* and urban *nonpoint source* (NPS) pollution, and TSSWCB manages NPS pollution related to agricultural and silvicultural activities. These agencies specifically must ensure that waterbodies across Texas meet these state designated water quality standards. These consist of two parts: designated uses and criteria. Designated uses are the purposes for which the waterbody will be used, including public water supply, contact recreation, aquatic life use, fish and shellfish consumption, and other general uses. Criteria are the indicators used to determine if the use is met, such as dissolved oxygen, temperature, pH and bacteria, which are typically represented by a numeric value that sets limits on pollutant loads. There is also a general criteria which are narrative and apply to all waters in the state. One example of a water quality standard is for bacteria. In order to meet the contact recreation use, bacteria levels must be below the criteria of 126 colony forming units of bacteria per 100 mL of water. This standard is in place to prevent human illness resulting from the ingestion of water while swimming, wading, or other water activities.

Every two years, TCEQ evaluates the water quality in streams, reservoirs, bays, and estuaries around the state, which is compiled into a statewide report, called the *Texas Integrated Report*, which is then submitted to the EPA for review. If a particular waterbody does not meet its designated use due to high pollutant levels, that waterbody is deemed impaired and placed on the CWA 303(d) list. Once placed on this list, the state must take remedial action to have that waterbody removed from the list within 13 years, usually through the development of a Total Maximum Daily Load (TMDL) or Watershed Protection Plan (WPP). In 2012, TCEQ evaluated 1,214 waterbodies throughout the state and found that 568 waterbodies were impaired, and 45% of the impairments were due to high bacteria levels.

Eutrophication is the enrichment of an aquatic ecosystem with nutrients (nitrogen and phosphorus) that accelerates the growth of algae and aquatic plants. Once these organisms die and begin decomposing, they begin to use the oxygen in the water. If levels get too low, fish and other aquatic life can no longer survive.

Excessive levels of bacteria are the leading cause of impairments in Texas, and humans, livestock, exotic animals, and wildlife all contribute bacteria to waterbodies. In addition, sediment and nutrients are significant sources of pollution in Texas, which can contribute to *eutrophication* problems and loss of aquatic habitats, as well as a loss in aesthetic and recreational value. Sediments also reduce the water storage capacity in reservoirs as they are deposited and leave less space for water. Toxic and hazardous substances, such

as pesticides, are pollutants that can be harmful to human health and the environment and contribute to impairment.

Pollutants interact with the chemical, biological, and physical characteristics of water, also known as parameters, to cause water quality problems that ultimately affect the economic benefits gained from waterways. It is difficult and expensive to directly measure these pollutants in the stream, therefore, researchers focus on different parameters in the water that are impacted by the amount of pollutants in the water, also known as the pollutant load (Table 1). For a complete description of each of these parameters, see the *Texas Watershed Steward Handbook* (B-6203) available at http://tws.tamu.edu.

Table 1. Common chemical, physical and biological water quality parameters measured to understand levels of water quality.

Parameter	Importance
Precipitation	Affects the rate and volume of water received into a watershed.
Stream Flow	The volume and velocity of water moving past a point over time. Volume and velocity affects the concentration of pollutants in the water.
Temperature	Affects the rate of many chemical and biological reactions and the ability to support aquatic life.
Fecal bacteria	Indicates the potential presence of pathogenic organisms that may cause illness in humans if water is ingested.
Nutrients	Generally refers to nitrogen and phosphorus. Excessive levels of both can result in eutrophication that can lead to depletion in oxygen levels once plants start decomposing.
Electrical conductivity	Measure of the solution's ability to conduct an electrical current, which is affected by the amount of total dissolved solids (TDS) in the water. The higher the level of TDS, the higher the level of conductivity. Useful for determining the suitability of water for irrigation and drinking.
Dissolved oxygen	Measure of dissolved gaseous oxygen in the water. An adequate level of dissolved oxygen is important for supporting aquatic life. Affected by numerous factors, including volume and temperature of water.
pH	Estimate of the acids and bases in a solution. If the water is too acidic or too basic, aquatic plants and animals can be seriously harmed or killed.
Turbidity	Affected by suspended solids. When combined with physical analyses and flow measurements, turbidity can be used to estimate sediment loads and watershed erosion. Higher levels of sediment often are associated with other pollutants, such as bacteria, nutrients, and toxic substances.

What is Watershed Monitoring?

NPS pollution does not originate from a clearly defined, fixed point and can come from different places across the landscape that may or may not be easily identifiable. Watershed monitoring studies are needed to understand how different land uses in urban and rural areas contribute to water quality, and which best management practices (BMPs) will be most effective at preventing or reducing NPS pollutant loads.

Watershed monitoring studies "evaluate the effectiveness of the BMP implementation efforts over time, measured against the criteria established to determine whether loading reductions (of pollutants) are being achieved over time, and substantial progress is being made toward attaining water quality standards." In other words, monitoring programs track the progress being made towards reducing pollutant loads. In addition to landowners investing in watershed BMPs, many are implemented through the financing of taxpayer dollars from government agencies such as the TSSWCB, TCEQ, the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS), and the EPA. Understanding which BMPs are the most cost-effective and provide the greatest improvement in water quality is important to determine the investment required to achieve a healthy watershed.

Monitoring Methods

Two methods are commonly used for watershed monitoring studies: 1) Edge-of-Field (EOF), and 2) Continuous In-stream. *EOF* monitoring stations collect data from individual fields or small watersheds and not in the waterbody itself. These stations measure runoff and rainfall from which an estimate of infiltration can be calculated (Figure 1). Directly measuring runoff provides a much better understanding of how different land uses and vegetation types

Figure 1. Edge-of-field instrumentation typically consists of a solar- or battery-powered system and an electronic datalogger recording rainfall and runoff through a V-notch in a flume or weir. Photos by Texas A&M AgriLife Research.

influence runoff and pollutant loads since it is difficult to determine once the runoff mixes together with water in the creek.

An EOF station consists of a solar-/battery-powered system and an electronic datalogger that records rainfall and runoff quantities by diverting the runoff from a small watershed into a flume, or weir, where sensors calculate how much water is flowing through. It may also utilize an automated water sampling device to collect water samples for further analyses. Samples are retrieved and processed in a laboratory for pollutants, like nutrients, sediment, and pesticides.

The quantity and quality of surface runoff may be indicative of the effect of plants or the particular landuse in practice. Eroded sediment is a prime concern because of downstream effects including: increased turbidity, nutrient chemical transport, and the deposition of sediments into waterways and reservoirs, resulting in reduced water storage capacity. Understanding how different land uses contribute to the health of the aquatic environment will help landowners improve water quality.

On cropland, for instance, research has shown that no-till planting has less runoff and erosion and greater infiltration than conventionally-tilled fields, resulting in higher crop yield. On rangeland, a study in the Edwards Plateau showed that sites with bunchgrasses had 20% more infiltration than sodgrass dominated sites, allowing the soil to hold more water and increase forage production.

Continuous in-stream monitoring is a more permanent system that directly collects water quality data in the creek at frequent intervals, such as every few minutes. This is important because water quality parameters change constantly and requires frequently repeated measurements over a long period of time for accurate assessment. For example, dissolved oxygen levels in water fluctuate throughout the day. Oxygen levels are highest at dusk after aquatic plants have been producing oxygen by photosynthesis. Levels are lowest at dawn, as oxygen production ceases at night (Figure 2).

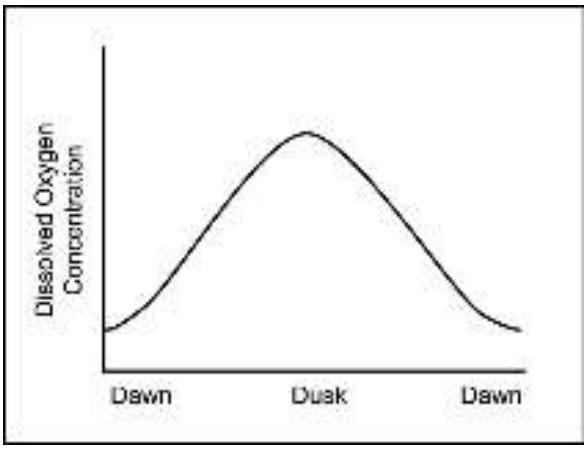


Figure 2. Dissolved oxygen levels are highest at dusk and lowest at dawn.

Datalogging equipment allows for collection and retrieval of continuous data using satellite or cellular data transfer and rapid distribution via the Internet. Instrumentation typically consists of a solar-/battery-powered system and an electronic datalogger coupled with a multi-parameter probe. Parameters monitored can include pH, electrical conductivity, dissolved oxygen, temperature, flow, precipitation, and turbidity (Table 1). Information delivered in near real time by continuous monitoring systems can help land managers make better decisions regarding when to respond to situations or conduct investigations relevant to human or environmental health (i.e., sample for industrial spills, bacterial populations, or nutrient levels).

Resolving NPS pollution problems takes time, and many projects fail to meet expectations for water quality improvement due to the lag time between the implementation of BMPs and the response of water quality parameters. Therefore, it is vital to conduct an in-stream monitoring program for a number of years to observe changes. Combined with the EOF stations, the continuous in-stream equipment can provide valuable insight into the impacts of land management on hydrology in a watershed.

Common Monitoring Study Designs

To properly evaluate the effectiveness of BMPs or an improvement in water quality, it is vital to have a good study design that will produce high quality data. The right study design will depend on the pollutants of concern, the length of the monitoring period, the size of the watershed or study area, and if the design will accurately attribute changes in water quality due to the implementation of BMPs. Monitoring programs are complex and expensive; therefore, it is important to select the appropriate design so that the money and time invested are well spent. Three common study designs are: 1) before and after implementation, 2) upstream/downstream, and 3) paired watersheds.

Before and After Implementation

With a before and after design, water quality data from one in-stream station is collected for a period of time before and after BMPs are implemented. The station will be downstream of where management activities are occurring (Figure 3). Two to three years is needed for these studies both before and after implementation so weather pattern differences can be taken into account and have an adequate amount of data for a strong statistical test to base recommendations on.

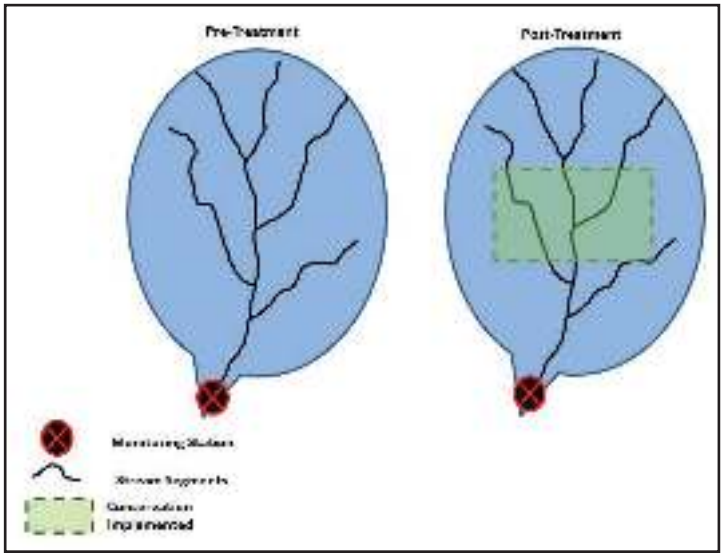


Figure 3. Basic diagram of a before and after study design.

Upstream/Downstream

As opposed to before and after, an upstream/downstream study design requires two stations, one upstream of the area where the BMPs are implemented and one downstream (Figure 4). This is valuable for knowing the amount of pollutants coming from areas upstream of the treatment area, but also to assess the beneficial effect that BMPs have immediately downstream of the treatment area. A time period of 2–3 years is required before implementation to establish a baseline, and another 2–3 years after implementation to assess the effects of the BMPs.

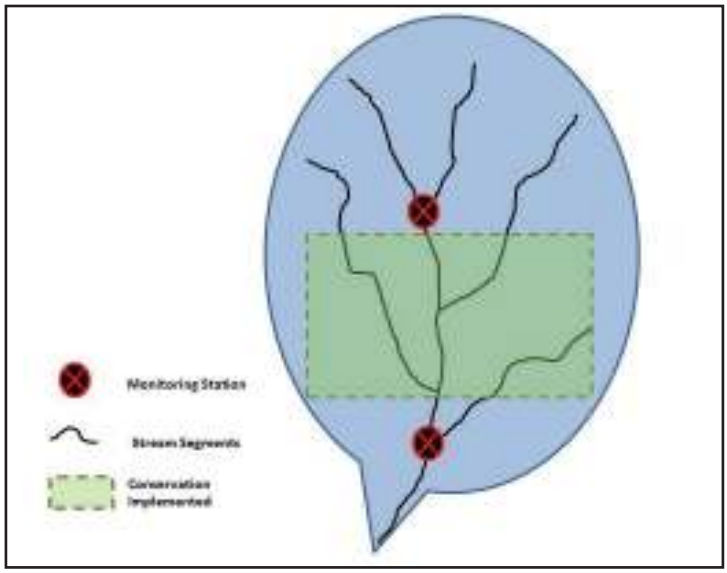


Figure 4. Basic diagram of an upstream/downstream study design.

Paired Watersheds

A paired watershed design studies two watersheds having similar land uses (Figure 5). A station is installed at the outlet of each watershed. One watershed will act as the "control," meaning that the land use will remain unchanged. The other watershed is the "treatment" area where the BMPs will be established. Before BMPs are used, both watersheds are monitored during the "calibration" period. After

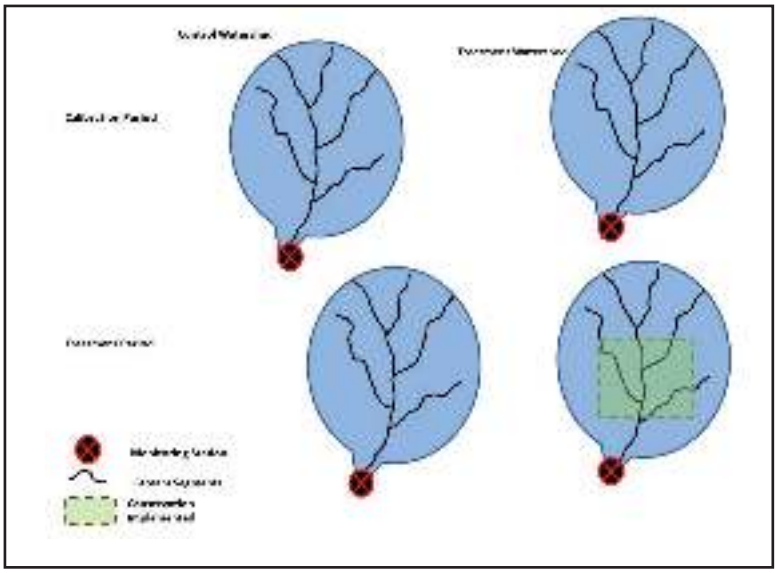


Figure 5. Basic diagram of a paired watershed study design.

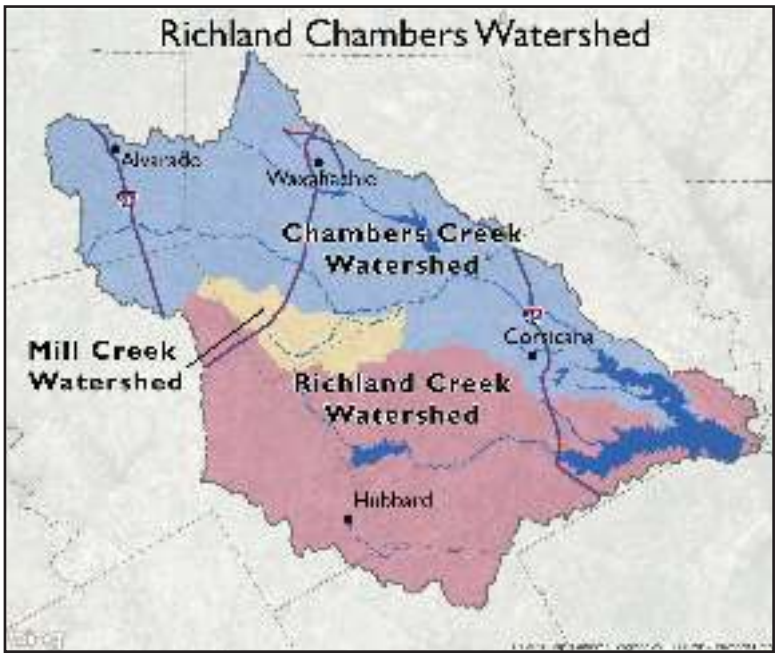


Figure 6. The Richland-Chambers Reservoir watershed encompasses 1.27 million acres and includes parts of six counties. Map produced by the Texas A&M Institute of Renewable Natural Resources.

calibration, the treatment period begins when BMPs are implemented in the treatment watershed. Management remains the same in the control watershed. During the treatment period, both watersheds are compared to evaluate differences in water quality due to management measures. The length of both periods is normally 2–3 years.

Each study type has its own advantages and disadvantages, but all are expensive and require multiple years to truly assess improvements in water quality (Table 2). Nevertheless, monitoring is a vital component to watershed planning efforts and is needed to understand how management practices impact water quality.

Example of Watershed Monitoring

One example of current research is in the Mill Creek watershed in Navarro County, which drains into the Richland-Chambers Reservoir (Figure 6). This reservoir is a major water source for 1.6 million residents in Fort Worth and surrounding communities in Tarrant County, yet private landowners manage 97% of the watershed. This is one example of the strong urban-rural connection that exists across Texas as rural lands provide water for the urban areas.

Texas A&M AgriLife Research scientists have established three EOF monitoring stations on a ranch in the Mill Creek watershed in Navarro County. Once rain hits the ground, it will either infiltrate, runoff, or evaporate. Understanding how vegetation influences the water cycle and the lands ability to capture and hold water is critical to the sustainable management of natural resources. In this

Table 2. Comparison table of the advantages and disadvantages of the three monitoring study types.

Monitoring Study Type	Advantages	Disadvantages
Before/After	Only one monitoring station is used	Does not take activities upstream of implemented BMPs into account Weather patterns may affect data between periods
Upstream/Downstream	Takes upstream activities into account	The additional station requires more costs for labor and equipment
Paired Watershed	Takes weather patterns between periods into account	Management activities in the control watershed must remain constant during the study period

case, three vegetation communities are being monitored; tall-grass prairie, mid-grass prairie and mid-grass/mesquite savannah (Box 1). The monitoring stations collect precipitation and runoff data to estimate how much of the rainfall is captured on the land by infiltration and lost by evapotranspiration and runoff.

Detailed information can be gathered from these monitoring systems, such as the timing of rainfall and the resulting runoff/discharge during the rainfall event (Figure 7). The blue dotted line from the top of each location shows when the rainfall took place and the intensity. The solid colored line in each component shows the amount of runoff/discharge from each site and when it occurred relative to the precipitation during the event.

Box 1. Description of plant communities on three monitored watersheds in Navarro County.

Not all grasses are created equal and at this ranch in Navarro County, researchers are monitoring three different plant communities to evaluate differences in rates of rainfall and runoff rates from each site.

With tallgrasses, livestock should not graze below 12–14 inches of growth to keep plants healthy. At this site, the dominant tallgrass species are little bluestem, meadow dropseed, and indiangrass. The size of this watershed is 0.4 acres.

With midgrasses, livestock should not graze below 6–8 inches of growth to keep plants healthy. At this site, the dominant midgrass species are Texas cupgrass, Texas wintergrass, and silver bluestem. The size of this watershed is 3.3 acres.

Midgrass/mesquite savannah contains mostly midgrass species but also has woody encroachment by mesquite shrubs/trees. This is due to a lack of prescribed burning that would normally keep brush levels low. Overgrazing also enables woody encroachment by reducing competition from grasses and forbs and exposing soil leading to brush establishment. Without burning or other brush control methods, mesquite and other woody species may eventually dominate a site, resulting in less cattle forage and less useable wildlife habitat. At this site, the dominant plant species are KR bluestem (invasive), Texas wintergrass, and mesquite. The size of this watershed is 1.5 acres.

Figure 8 summarizes the results from Figure 7 of the single rainfall event across the three vegetation communities. In this case, the tall-grass prairie and midgrass/mesquite savannah systems discharged the majority of the precipitation for the single rainfall event, whereas the midgrass system retained a majority of the precipitation. Many factors influence infiltration and runoff including the soil moisture prior to a rainfall event, soil type, slope, and the different plant species. It is important to understand that these are for a single rainfall event and not representative

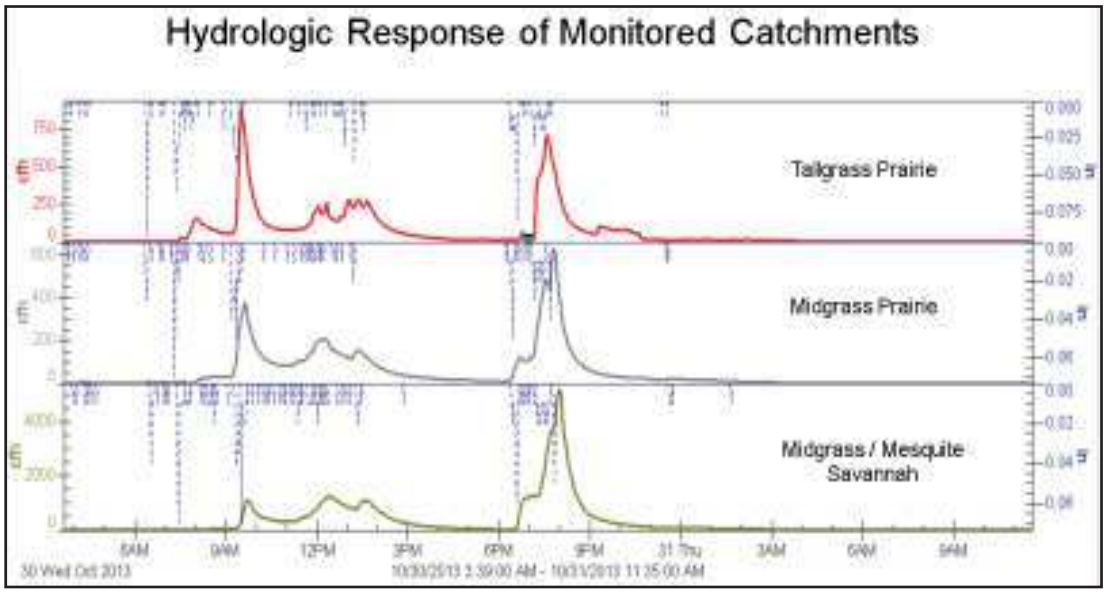
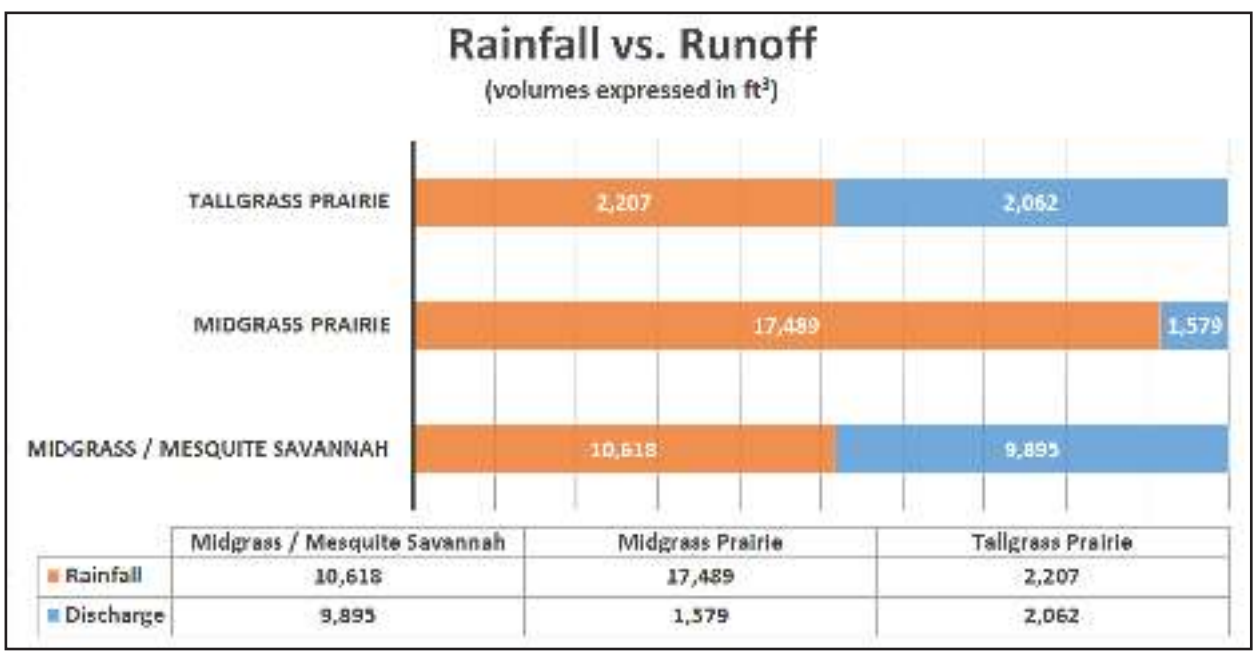


Figure 7. Example of data collected from three different EOF stations in Navarro County for a single rain event. Blue dotted lines represent rainfall and correspond to the scale on right vertical axis in inches. Solid colored lines represent the volume of runoff coming from the respective watersheds and correspond to the scale on the left vertical axis in ft^3/hour.



	Midgrass / Mesquite Savannah	Midgrass Prairie	Tallgrass Prairie
Rainfall	10,618	17,489	2,207
Discharge	9,895	1,579	2,062

Figure 8. This bar graph summarizes the results from Figure 7. In this example, the midgrass prairie captured more rainfall and therefore had less runoff than the other two sites during this rainfall event. This may not always be the case and different factors play a role in the infiltration/runoff rates than vegetation types alone. It is important to note that although these watersheds all received about 1.5 inches of rainfall in this one event, the volumes given are very different due to the varying watershed sizes (see Box 1). There is a greater volume of water from the midgrass prairie watershed since it has more land area than the smaller tallgrass prairie watershed.

of the individual systems over time, but instead is a demonstration of the kind of information that can be derived from watershed monitoring studies. To obtain a full understanding of how these vegetation communities influence the infiltration and runoff rates requires continuous monitoring of multiple rainfall events over time. This valuable information can help land managers understand how their vegetation management is affecting the ability of the land to capture and hold water during varying rainfall events and guide them to enact management practices to capture more rainfall, which will lead to greater rangeland health and sustainability.

In general, practices can be implemented to reduce erosion, and increase infiltration and organic matter, such as:

1. Establishing a proper stocking rate for grazing animals. Download the AgriLife Extension "Stocking Rate Calculator for Grazing Livestock" app from iTunes to quickly and easily make this determination.
2. Maintaining plant cover to protect soil and hold moisture.
3. Rotating cattle among pastures to allow rest for plants.
4. Increasing plant diversity either by planting seeds or altering grazing patterns and conducting prescribed burns.
5. Minimizing soil disturbance by using reduced or no-till cropping practices.
6. Managing brush cover levels to allow more grass and forb growth.

Conclusion

Watershed monitoring studies provide valuable information to land managers in their efforts to optimize agricultural production and the goods and services that are provided by landscapes (clean water, wildlife habitat, etc.). Implementing land management practices that increase infiltration and reduce erosion will help landowners make their operations more profitable and sustainable. Cities and water districts may also find this information valuable for understanding which management practices would be best to implement when partnering with private landowners to keep waterbodies healthy, and when identifying critical areas for open space preservation, which will reduce flooding hazards and improve water quality and quantity. Watershed planning efforts lead to clean, abundant water for Texas for years to come and should be considered from the individual landowner perspective on up.

Additional Resources

- Texas A&M Blackland Research and Extension Center: blackland.tamu.edu
- Texas Watershed Steward: tws.tamu.edu
- Lone Star Healthy Streams: lshs.tamu.edu
- Texas Riparian and Stream Ecosystem Education: texasriparian.org/riparian-education-program
- Texas Land Trends texaslandtrends.org
- Texas Stream Team: txstreamteam.meadowscenter.txstate.edu

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Acknowledgements

The authors would like to thank Dr. Jay Angerer (Texas A&M AgriLife Research – Blackland Research and Extension Center, Temple, Texas) and Dr. Megan Clayton (Texas A&M AgriLife Extension Service – Corpus Christi, Texas) for their thoughtful reviews of this publication. The authors would also like to thank Leslie Lee (Texas Water Resources Institute) for designing this publication.

This publication was developed as part of the Building Partnerships for Cooperative Conservation Initiative in the Trinity River Basin, with funding support from the U.S. Environmental Protection Agency through a Clean Water Act 319(h) grant administered by the Texas State Soil and Water Conservation Board and managed by the Texas Water Resources Institute.

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