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Council of Governments

Integrating Transportation and Stormwater Infrastructure

Assessment of Flood Risk Increase and Evaluation of Green Stormwater Infrastructure as a Mitigation Strategy

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Assessment of Flood Risk Increase and Evaluation of Green Stormwater Infrastructure as a Mitigation Strategy: A SWAT Modeling Approach

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Executive Summary

Rapid urbanization is one of the most significant drivers of increased stormwater runoff and flood risk in contemporary urban environments. This report presents a comprehensive assessment of projected increases in flood risk between 2016 and 2070 resulting from accelerated urban development. It evaluates the effectiveness of Green Stormwater Infrastructure (GSI) as a sustainable mitigation strategy. Using the Soil and Water Assessment Tool (SWAT) integrated with a Low Impact Development (LID) module, this study quantifies changes in water yield at the subbasin level under projected land use scenarios and simulates the flood mitigation performance of GSI under three implementation scenarios: maximum potential GSI (100%), 75% potential GSI, and 50% potential GSI. The findings of this report are intended to inform urban planners, environmental engineers, policymakers, and municipal water resource managers in developing evidence-based strategies for sustainable urban water management.

1. Objectives

The primary objectives of this study are as follows:

1. To quantify the projected increase in water yield and flood risk at the subbasin level between 2016 and 2070 under projected urban land use changes using SWAT modeling.
2. To evaluate the effectiveness of GSI in reducing stormwater runoff and mitigating flood risk using the SWAT-LID module.
3. To compare GSI performance across three implementation intensity scenarios: maximum potential GSI (100%), 75% potential GSI, and 50% potential GSI.
4. To provide evidence-based recommendations for GSI implementation as part of an integrated urban flood management strategy.

2. SWAT Modeling for Urban Hydrology

The Soil and Water Assessment Tool (SWAT) is a widely used watershed model developed by the United States Department of Agriculture Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research. SWAT simulates hydrological processes, including surface runoff, infiltration, evapotranspiration, groundwater recharge, and streamflow, at the subbasin level and has been extensively applied to assess the hydrological impacts of land use change and climate variability (Gassman et al., 2007).

The integration of a Low Impact Development (LID) module within the SWAT framework has expanded the model's capability to simulate the performance of individual and multiple GSI practices at the watershed scale (Her et al, 2017). The SWAT-LID model allows for the explicit representation of GSI practices within hydrological response units (HRUs) and can simulate their effects on runoff generation, peak flows, and water yield under a range of land use and climate scenarios. This capability makes SWAT-LID particularly well-suited for the assessment of GSI performance under future urbanization scenarios.

3. Data

- **2016 Land Use Land Cover:** Representing the baseline condition, the 2016 land use map reflects the existing distribution of urban, agricultural, forested, and other land cover types within the watershed at the beginning of the study period.
- **2070 Projected Land Use:** Representing the anticipated distribution of land cover under rapid urbanization scenarios, provided by University of Texas Arlington.
- **Digital Elevation Model (DEM):** Used for watershed delineation, subbasin definition, and stream network generation, extracted from Hec-HMS models provided by US Army Corps of Engineers and Freese and Nichols
- **Soil Data:** Soil classification, hydrologic soil group, and physical properties used to parameterize soil water dynamics within SWAT, sourced from SSURGO (Soil Survey Geographic Database)
- **Rainfall Data:** Designed 100-year two-day event used to drive the SWAT model, extracted from Hec-HMS models provided by US Army Corps of Engineers and Freese and Nichols
- **GSI Potential Data:** Spatial extent and physical characteristics of proposed GSI practices used to parameterize the SWAT-LID module, sourced from GSI potential analysis of Texas A&M AgriLife

4. Methodology

4.1 SWAT Model Setup

The SWAT model was configured for the study watershed using the data described in Section 3. The model setup involved the following steps:

1. **Watershed Delineation:** The watershed was delineated from the DEM into multiple subbasins, each draining to a defined outlet point. The delineation process defined the spatial extent and connectivity of subbasins within the watershed.

2. **HRU Definition:** Hydrological Response Units (HRUs) were defined within each subbasin based on the unique combination of land use, soil type, and slope class. HRUs serve as the fundamental spatial unit for hydrological simulation within SWAT.
3. **Model Parameterization:** The SWAT model was parameterized using the available soil, climate, and land use data. Key parameters governing surface runoff generation (e.g., Curve Number), evapotranspiration, groundwater recharge, and channel routing were assigned based on literature values and local data.
4. **Model Calibration and Validation:** The SWAT model was calibrated against WHA streamflow data to optimize model performance. Calibration involved systematic adjustment of sensitive model parameters to minimize the difference between simulated and observed streamflow. Model performance was evaluated using standard statistical metrics, including Nash-Sutcliffe Efficiency (NSE), Percent Bias (PBIAS), and the Ratio of the Root Mean Square Error to the Standard Deviation Ratio (RSR).

4.2 Baseline and Future Scenario Simulations

The calibrated and validated SWAT model was applied to simulate water yield and runoff under two land use scenarios:

- **Scenario 1 (Baseline – 2016):** SWAT simulation using the 2016 land use map to establish the baseline hydrological condition of the watershed.
- **Scenario 2 (Future – 2070):** SWAT simulation using the projected 2070 land use map to quantify the hydrological impacts of rapid urbanization on water yield and flood risk.

The difference in simulated water yield between the 2016 and 2070 scenarios was calculated at the subbasin level and expressed as a percentage increase, providing a spatially explicit assessment of the flood risk amplification associated with projected urbanization.

4.3 SWAT-LID Module for GSI Simulation

Three GSI implementation scenarios were simulated to evaluate the relationship between implementation intensity and flood mitigation effectiveness:

- **GSI Scenario 1 – Maximum Potential GSI (100%):** All feasible locations within the watershed where GSI practices can be technically and spatially implemented are assumed to be developed with appropriate GSI measures.
- **GSI Scenario 2 – 75% Potential GSI:** GSI practices are implemented across 75% of the feasible locations identified in the maximum potential scenario.
- **GSI Scenario 3 – 50% Potential GSI:** GSI practices are implemented across 50% of the feasible locations identified in the maximum potential scenario.

For each GSI scenario, the SWAT-LID model was run under the 2070 land use conditions to simulate the reduction in water yield and flood risk achieved by GSI relative to the unmitigated 2070 scenario.

5. Results

5.1 Projected Increase in Water Yield from 2016 to 2070

The SWAT model simulations under the 2016 and 2070 land use scenarios reveal a significant increase in water yield at the subbasin level as a consequence of rapid urbanization, shown in Figure 1. The conversion of natural and agricultural land to urban uses results in widespread increases in impervious surface coverage across the watershed, substantially reducing infiltration and increasing surface runoff generation.

The increase in water yield exhibits significant spatial variability at the subbasin level, reflecting the heterogeneous nature of projected urban development across the watershed. Subbasins experiencing the greatest proportional conversion from natural or agricultural land to urban uses demonstrate the largest percentage increases in water yield, while subbasins where urbanization is less intensive show more moderate increases.

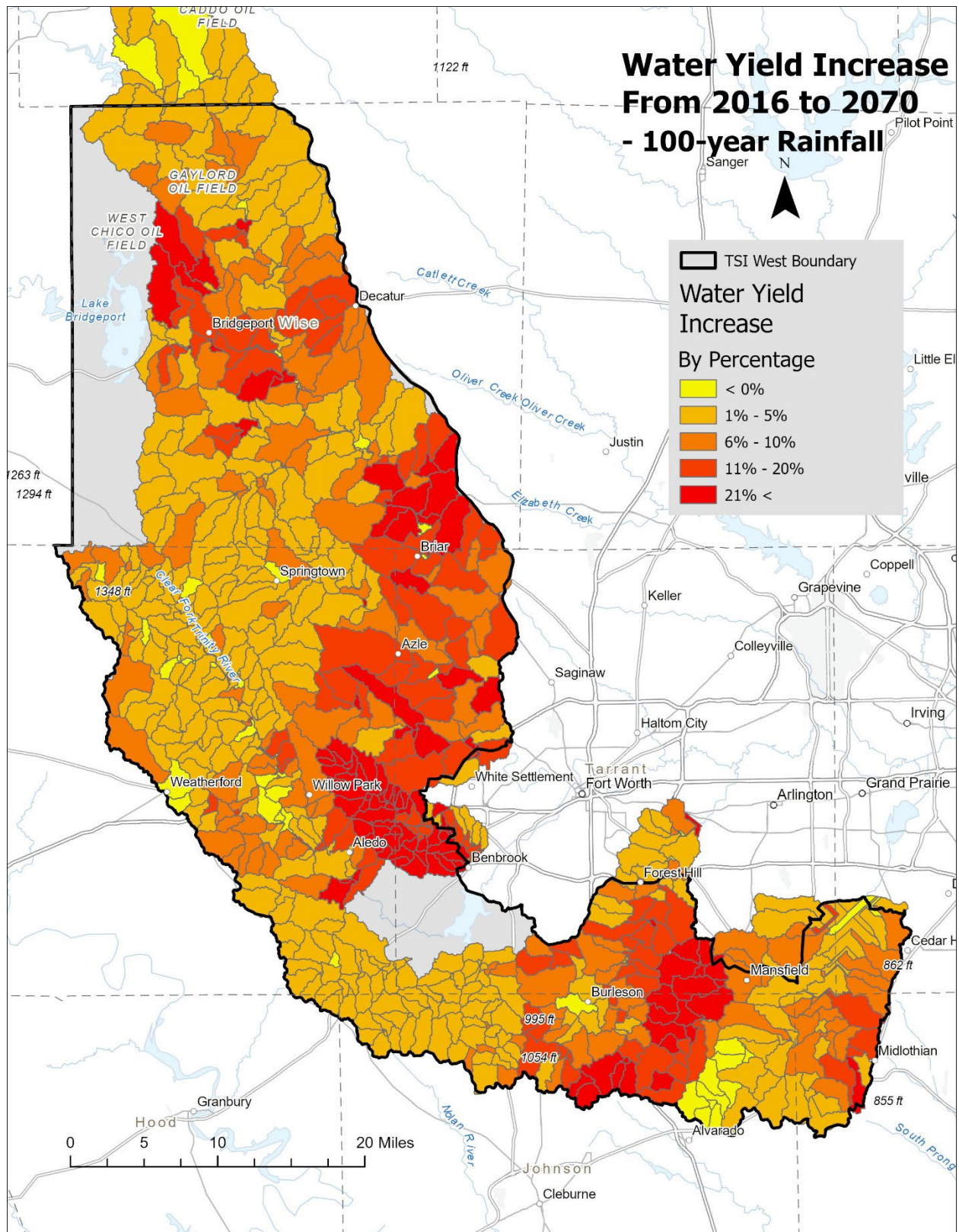


Figure 1. Water Yield Increase by Percentage From 2016 to 2070

5.2 Maximum GSI Potential

The water yield increase demonstrates that without mitigation, rapid urbanization will significantly amplify flood risk across the watershed, with the most pronounced impacts concentrated in areas of intensive urban development. In response, Figure 2 presents the Maximum GSI Potential Coverage for 2070, providing a subbasin-level assessment of the feasible extent of GSI implementation across the TSI West area. The darkest green areas (>0.05 fraction) — representing the highest GSI potential — are concentrated primarily in the central and southern portions of the study area.

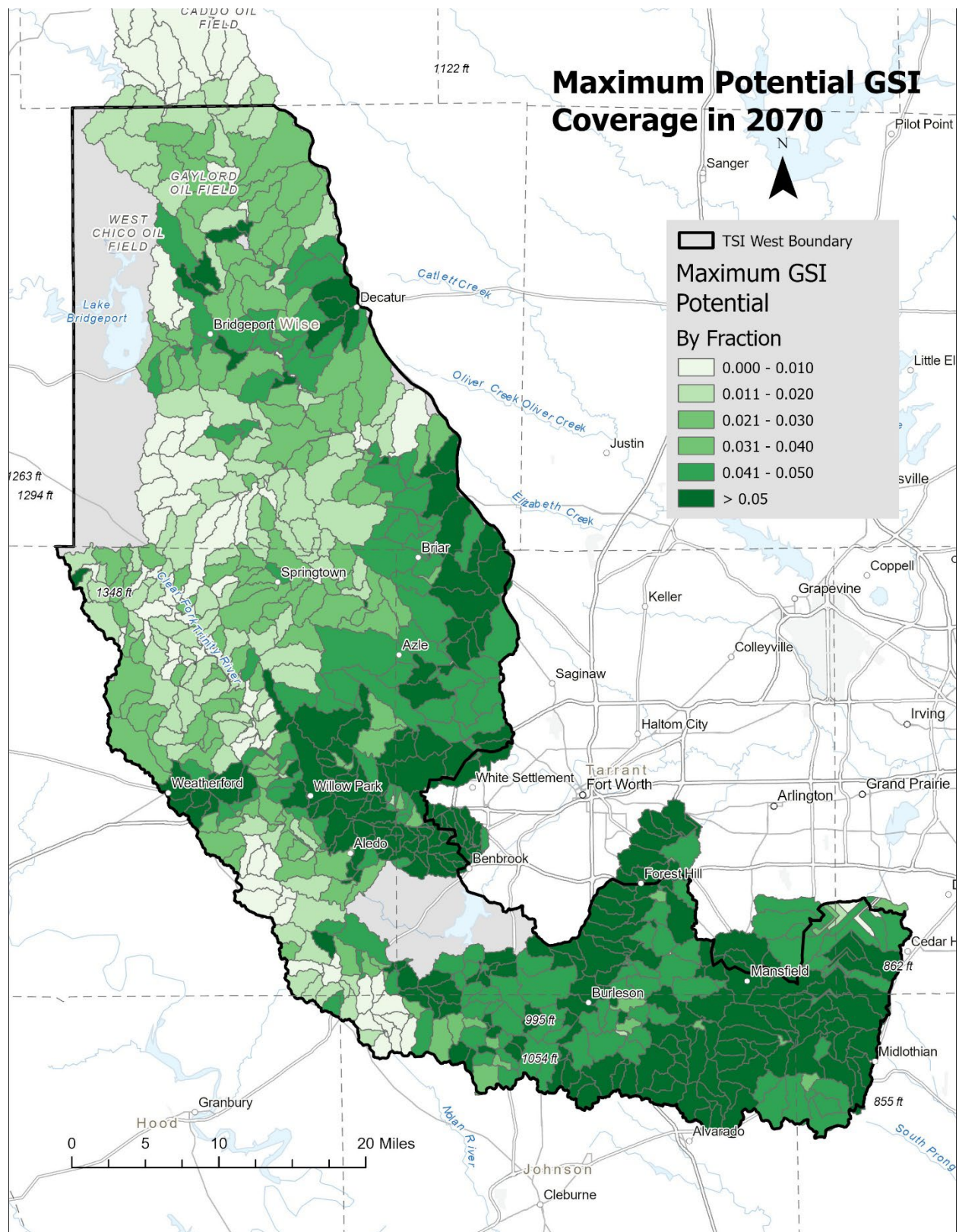


Figure 2. Maximum GSI Potential

5.3 GSI Performance under Maximum Potential Implementation (100%)

The SWAT-LID simulation of maximum potential GSI implementation represents the scenario where all feasible locations within the watershed are equipped with appropriate GSI practices. Under this scenario, the model simulates the full potential of GSI to counteract the hydrological impacts of urbanization between 2016 and 2070.

Figure 3 illustrates the spatial distribution of water yield reduction (%) achieved through Maximum Green Stormwater Infrastructure (GSI) implementation across the TSI West Boundary watershed under a 100-year rainfall event, covering areas across Wise, Parker, Tarrant, and Johnson Counties in north-central Texas. Water yield reductions range from less than 1% to greater than 15% depending on subbasin location. The most significant reductions are observed in the Bridgeport/Wise area in the northern portion of the watershed; Briar, Azle, and Aledo along the central eastern corridor; and Forest Hill, Mansfield, and Midlothian in the southeastern subbasins. These subbasins benefit most from maximum GSI deployment, reflecting their higher urbanization levels and greater concentration of GSI practices.

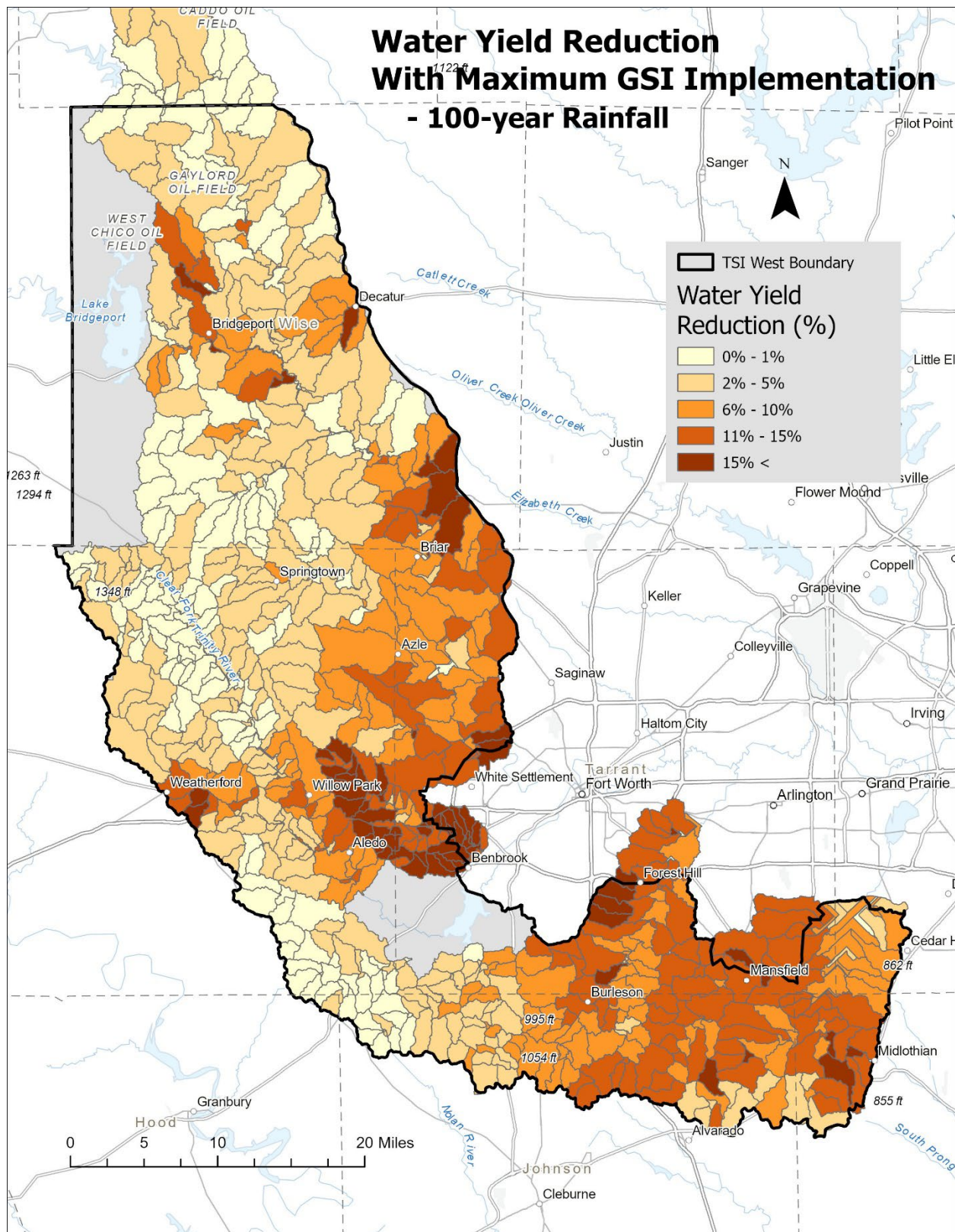


Figure 3. Water Yield Reduction with Maximum GSI Implementation

5.4 GSI Performance under 75% Potential Implementation

The 75% GSI implementation scenario reflects a high but practically attainable level of GSI deployment, accounting for limitations related to land availability, property ownership, and institutional capacity. Under this scenario, GSI practices are implemented at 75% of the feasible locations identified in the maximum potential scenario.

The 75% GSI scenario produces water yield reductions that are intermediate between the 50% and maximum GSI scenarios, as expected, confirming a generally proportional relationship between GSI implementation intensity and flood mitigation performance. The spatial distribution of high-performing subbasins remains consistent across all three scenarios, with the same core areas around Briar, Azle, Forest Hill, and Mansfield driving the greatest reductions regardless of implementation level.

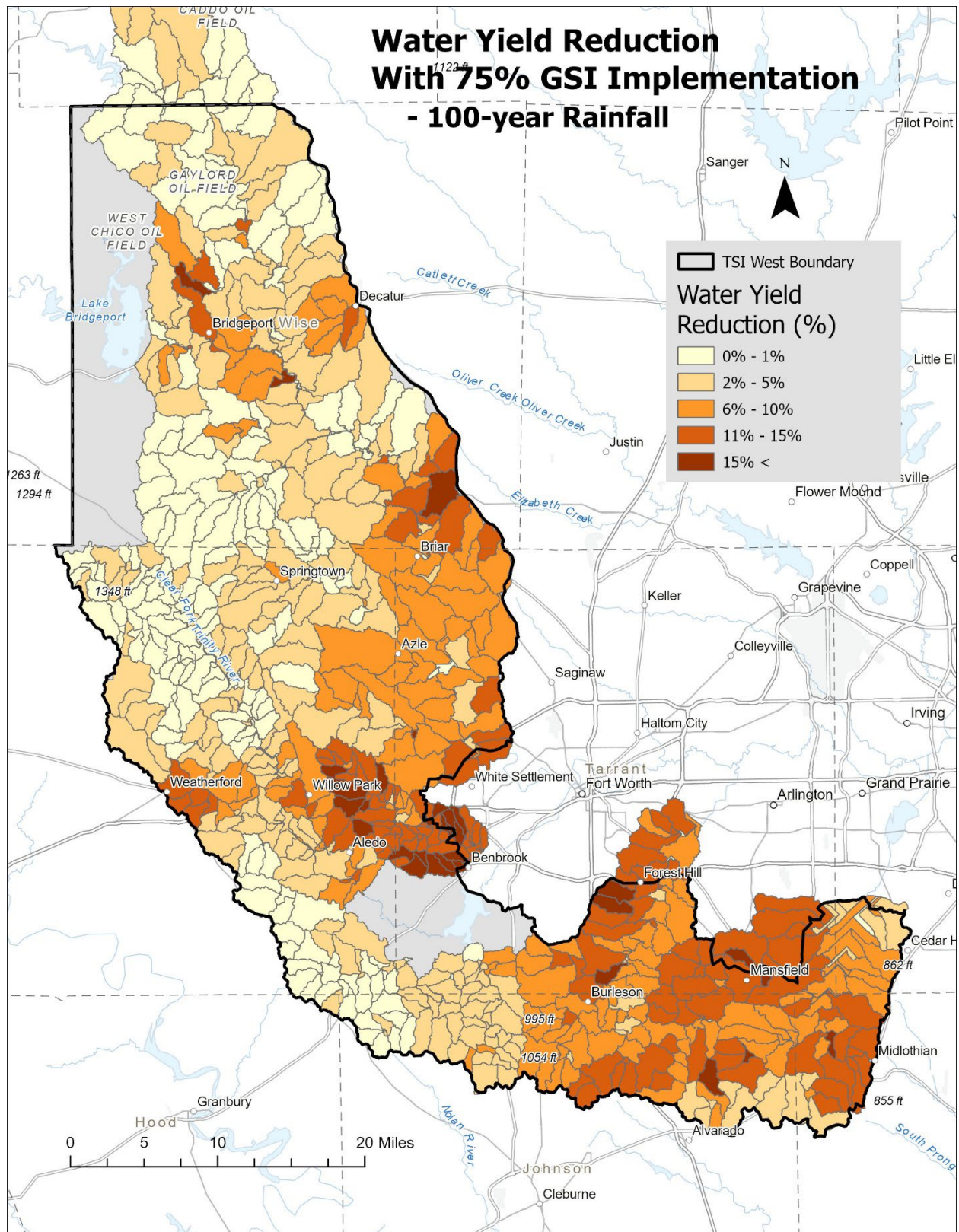


Figure 4. Water Yield Reduction with 75% GSI Implementation

5.5 GSI Performance under 50% Potential Implementation

The 50% GSI implementation scenario represents a moderate level of GSI deployment, reflecting conditions where resource constraints, competing priorities, or limited regulatory drivers restrict the scale of GSI implementation to half of the technically feasible maximum.

The 50% GSI scenario produces the lowest overall water yield reductions among the three implementation scenarios, as expected. The spatial pattern of high-performing subbasins remains consistent across all scenarios, with the same core areas — Briar, Azle, Forest Hill, and Mansfield — consistently achieving the greatest reductions. Compared to the 75% scenario, the 50% scenario shows a discernibly reduced spatial extent of moderate-to-high reduction areas, particularly across the central corridor and southeastern subbasins. The incremental difference in water yield reduction between the 50% and 75% scenarios is more pronounced than the difference between the 75% and maximum scenarios, suggesting that initial increases in GSI implementation intensity yield proportionally greater marginal benefit.

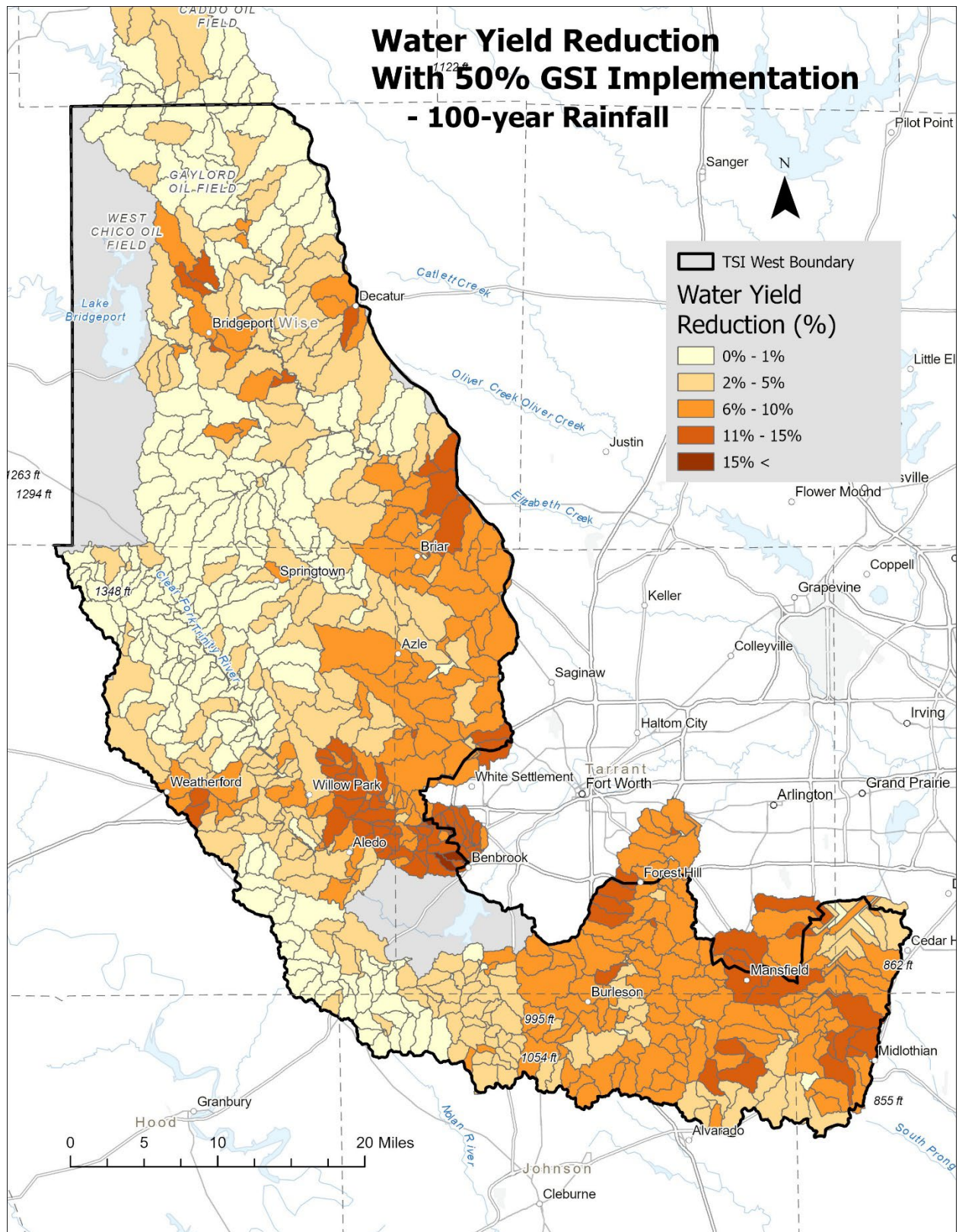


Figure 5. Water Yield Reduction with 50% GSI Implementation

Reference

Gassman, P. W., Reyes, M. R., Green, C. H., & Arnold, J. G. (2007). The Soil and Water Assessment Tool: Historical development, applications, and future research directions. *Transactions of the ASABE*, 50(4), 1211–1250. <https://doi.org/10.13031/2013.23637>

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