SPHEROS ENVIRONMENTAL

# Technical Memorandum

July 26, 2026 4063SLR01

To: Sarah Kouba, General Manager, Lone Star Groundwater Conservation District

From: Gretchen Miller, Ph.D., P.E., P.G., Spheros Environmental
Amir Sedaghatdoost, Ph.D., Spheros Environmental
Jordan Furnans, Ph.D., P.E., P.G., Windward Water Resources Engineering & Geoscience

Re: **Technical Review of the Hydrologic and Hydraulic Modeling for the Spring Creek Watershed Subsidence Impacts Study**

## Overview

Spheros Environmental ("Spheros") was asked to provide a detailed review of a series of documents prepared in August 2025 jointly entitled *Evaluation of Subsidence Impacts in the Spring Creek Watershed* (herein referred to as the "*Report*"). The *Report* was prepared by Michael Baker International on behalf of the Harris-Galveston Subsidence District and was authored by Manoj Kc and Mohamed A. Bagha ("*Authors*"). The stated purpose of the study was to "evaluate subsidence impacts on flood risk within the Spring Creek Watershed, an area along the northwestern border of Harris County." The five documents we reviewed, which make up *The Report*, are:

- Executive Summary
- Data Collection Summary Report
- Technical Memorandum #1: Methodology for Subsidence Grid Development ("*TM1*")
- Technical Memorandum #2: Development of Hydrologic and Hydraulic Models for Subsidence Scenarios ("*TM2*"), and
- Technical Memorandum #3: Hydraulic and Economic Impact Assessment for Subsidence Scenarios ("*TM3*").

The *Report* collectively attempts to assess whether, by how much, and where subsidence and development within the Spring Creek watershed will lead to increased flooding risk and potential property damage by 2070. In the following memo, we provide a detailed analysis of the scientific and technical veracity of the *Report* based on the existing technical literature and model documentation, commonly accepted modeling practices, and our experience. Our review focuses on assessing aspects of the *Report* related to hydrology, hydraulics, and groundwater only; it is not within our

expertise as water resources engineers to evaluate quantification of economic losses as put forth by the Authors.

Our criticism of the model falls along seven main dimensions, which address how the technical issues with the model likely impact the veracity of its conclusions. These are:

1. The calibration dataset is limited to two extreme events, whereas multi-event calibration is considered the standard of practice due to its added robustness.
2. The values used to calculate model error were not properly selected, leading to a potentially severe underestimation of the error percentage.
3. The error metrics used in the model were incomplete, lacking standard calculations like Nash-Sutcliffe efficiency and Root Mean Squared Error.
4. In many areas of the model, grid-cell resolution appears coarse relative to the watershed variability, and the impacts of grid-size selection were not assessed.
5. The "Manning's n" surface roughness parameters were outside established norms for their land use types without supporting documentation to show their appropriateness.
6. A scenario testing the impact of land development was not included, leading to unfairly attributing the majority of economic damages to subsidence.
7. The uncertainty inherent in the subsidence values used, and the modeling from which they were derived, was not discussed.

These issues are discussed in depth in the sections that follow.

## Issue 1: Limited Calibration Dataset

The hydrologic and hydraulic modeling framework presented in the *Report* would benefit from a more robust calibration and validation strategy to support confidence in long-term future flood-risk projections. The Authors report calibrating the Rain-on-Mesh (RoM) model using data from Hurricane Harvey (2017) and then performing a subsequent "check" against data from Hurricane Beryl (2024). Harvey is characterized as a high-magnitude historical event (approximately 100-500-year recurrence interval), while Beryl represents a substantially smaller event (approximately 5-10-year recurrence interval). Although the use of both an extreme and a moderate event is valuable, calibration against a single primary event and evaluation against a single secondary event does not sufficiently demonstrate the predictive robustness across the range of hydrologic conditions relevant to future flood-risk assessment. While the model matches these two events well in some, but not all, areas, the Authors did not demonstrate that the model performed well under a broader range of events.

Hydrologic and hydraulic models are commonly sensitive to event-specific conditions, particularly when parameterization includes infiltration assumptions, roughness values, rainfall translation, and routing approximations (Costabile and Macchione, 2015). Calibration to a single large event is likely to produce parameter values that reproduce one hydrograph well but do not generalize to storms of different magnitudes, durations, or spatial rainfall patterns. This concern is particularly relevant for

pluvial modeling in mixed urban and rural watersheds, where runoff response can differ substantially between short-duration convective events and prolonged regional storms. Because the stated objective of the *Report* was to assess future flood-risk changes associated with land subsidence through 2070, model reliability should be demonstrated across multiple hydrologic regimes rather than inferred from one major event. The lack of generalization across storms and the resulting lack of calibration metrics across storms does not allow proper assessment of the model's predictive ability under various conditions.

Multi-event calibration is widely recommended because parameter sets tuned to a single event may reproduce peak conditions yet fail to generalize across storms with different rainfall organization, antecedent moisture, or runoff dynamics (Moriasi et al., 2007; Dottori et al., 2013). Studies have shown that calibration using multiple events spanning a range of hydrologic conditions improves transferability of parameterization and better captures structural uncertainty in flood models. In particular, distributed flood models calibrated only to large historical events may reproduce flood peaks but underperform in runoff timing, recession behavior, or localized inundation under other storm types (Dottori et al., 2013). **Consequently, a calibration strategy based primarily on Hurricane Harvey may risk producing a model that is tuned for one storm type rather than for general watershed behavior.**

## Issue 2: Inappropriate Selection of Calibration Metrics

The calibration metric itself presents further concerns, calling into question whether model performance is evaluated in a manner directly relevant to flood hazard assessment. Based on the calibration summary tables presented in the *Report*, model error appears to be expressed as a percentage of observed water-surface elevation (relative to the NAVD88 datum). Although this approach produces small percentage differences numerically, it may understate practical hydraulic error because the denominator reflects a large absolute elevation rather than the flood-relevant hydraulic quantity of interest: water depth above channel invert, ground surface, or damage threshold elevations.

The formula for calculating the error percentage as shown in the *Report's* summary table (reproduced as Figure 1 below) is not provided. However, we reconstructed it to be:

$$Error\ Percentage\ = \frac{WL_{Modeled} - WL_{Measured}}{WL_{Measured}} \cdot 100$$

The issue with this calculation metric is that the full values of the modeled elevations ($WL_{modeled}$) and the measured elevations ($WL_{measured}$) relative to the datum were used. A more appropriate selection would have been the depth of water in Spring Creek channel ($D$) at the gage location, with error given by the equation:

$$Error\ Percentage = \frac{D_{Modeled} - D_{Measured}}{D_{Measured}} \cdot 100$$

For example, a difference of several feet between observed and modeled peak water-surface elevation may appear relatively minor when normalized against elevation. However, flood damages are governed not by elevation, but by inundation depth above local terrain, structure floors, roadway elevations, or channel controls. In practical terms, a 5–6 ft discrepancy in predicted water level may represent a substantial proportion of actual flood depth, even if the reported percentage error appears modest. Consequently, calibration metrics expressed relative to absolute water-surface elevation may overstate apparent model skill and obscure the magnitude of hydraulically meaningful error. From a hydraulic and flood-damage perspective, model skill is more appropriately evaluated relative to flood depth (e.g., stage above local channel invert, terrain elevation, or structural threshold elevation) than absolute elevation because damages are driven by inundation depth.

**Peak Stage Difference Summary Table**

| | | | Storm Event | | | | Error Percentage | |
|---|---|---|---|---|---|---|---|---|
| Gage Number | Location | Datum Adjustment applied | Harvey 2017 | | Beryl 2024 | | Storm Event | |
| | | NAVD88, 2001 to Geoid12b | Measured* | Modeled | Measured* | Modeled | Harvey 2017 | Beryl 2024 |
| USGS 8068390 | Bear Br at Research Blvd, The | -0.012 | 140.26 | 142.59 | 138.43 | 137.93 | 1.7 | 0.4 |
| USGS 8068400 | Panther Br at Gosling Rd, The | -0.011 | 137.48 | 139.83 | 135.32 | 134.65 | 1.7 | 0.5 |
| USGS 8068500 | Spring Ck nr Spring, TX | -0.026 | 111.49 | 116.86 | 87.35 | 97.91 | 4.8 | 12.1 |
| USGS 8068275 | Spring Ck nr Tomball, TX | -0.039 | 165.61 | 167.08 | 148.11 | 152.20 | 0.9 | 2.8 |
| USGS 8068450 | Panther Br nr Spring, TX | -0.023 | 117.10 | 123.81 | 107.44 | 108.41 | 5.7 | 0.9 |
| HCFCD 1074 | Walnut Creek at Joseph Road | -0.006 | 225.59 | 230.79 | 218.89 | 222.76 | 2.3 | 1.8 |
| HCFCD 1090 | Spring Creek at Hegar Road | -0.015 | 223.04 | 222.90 | 212.93 | 217.03 | 0.1 | 1.9 |
| HCFCD 1086 | Threemile Creek at FM 362 | -0.004 | 272.87 | 274.36 | 268.72 | 273.08 | 0.5 | 1.6 |
| HCFCD 1084 | Threemile Creek at Joseph Road | -0.004 | 242.10 | 244.09 | 238.30 | 241.49 | 0.8 | 1.3 |
| HCFCD 1076 | Birch Creek at Riley Road | -0.007 | 263.56 | 264.04 | 259.11 | 260.75 | 0.2 | 0.6 |
| HCFCD 1060 | Spring Creek at Kuykendahl Road | -0.02 | 140.86 | 143.61 | 121.60 | 125.04 | 2.0 | 2.8 |
| HCFCD 1050 | Spring Creek at I-45 | -0.026 | 111.43 | 117.51 | 87.35 | 98.67 | 5.5 | 13.0 |
| HCFCD 1040 | Spring Creek at FM 2978 | -0.037 | 154.26 | 155.96 | 136.06 | 140.91 | 1.1 | 3.6 |
| HCFCD 1070 | Spring Creek at SH 249 | -0.039 | 166.41 | 166.65 | 148.09 | 152.64 | 0.1 | 3.1 |
| Total Gages | 14 | | Within 5% | | | | 86% | |
| Total Storms | 2 | | Within 10% | | | | 93% | |
| No Data | 0 | | Within 20% | | | | 100% | |
| Data Points | 28 | | Greater than 20% | | | | 0% | |

*Datum adjustment applied

*Figure 1 – Reproduced Summary Table from Appendix A2 of Technical Memorandum 2, showing problematic calibration metric calculations using the "error percentage."*

Consider the HCFCD 1050 gage on Spring Creek at I-45. For Hurricane Harvey, the difference between the modeled and measured peak stage was 6.08 feet. This amount, when divided by the 111.43 ft measured water level, amounts to an error percentage of 5.5%; this is the error percentage provided in the *Report* summary table (Figure 1). However, as an example, consider if the elevation of the creek channel was instead 100 ft above the NAVD88 datum. The modeled depth for the event would have been 17.51 ft (117.51ft -100 ft), while the measured depth would have been 11.43 ft (111.43 ft -100 ft). This would result in an error percentage of 6.08 ft/11.43 ft = 53%, signifying that the modeled flooding depth overpredicted the observed flooding depth by 53%.

Such an overprediction is not indicative of a model that is sufficiently accurate to assess potential flooding damage, especially when flooding damages are assumed for areas where computed flooding depths exceed either 0.5 ft or 1.0 ft (e.g., Figure 2). To properly model flood damage extents defined by water depths of at least 0.5 ft within structures, it is necessary that the accuracy of the HEC-RAS model-predicted peak water levels be lower than this 0.5 ft threshold.

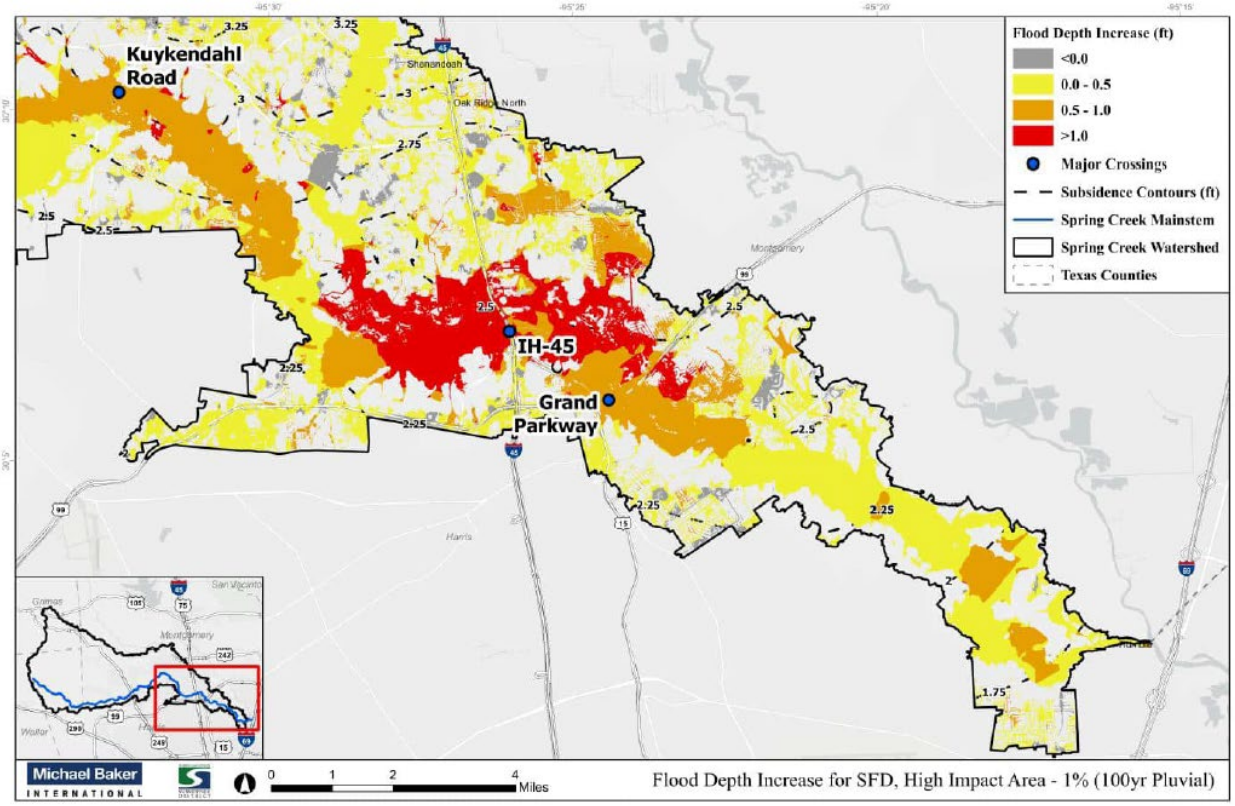



**Figure 9: Flood Depth Increase Between Baseline and Subsidence with Future Development (SFD) Scenario at 100-Year Event (Pluvial), East of Tomball Parkway**

*Figure 2 – Reproduced Figure 9 from Technical Memorandum #3, showing the largest flood depth increase around the area where Spring Creek crosses under I-45.*

This issue is particularly important because a model may appear to satisfy calibration criteria under a datum-based metric while still exhibiting uncertainty comparable to, or exceeding, the flooding thresholds used to estimate economic damages. If predicted stage discrepancies materially exceed the flood depths associated with damage categorization, confidence in localized economic loss estimates and future flood attribution may be reduced. **Model performance should be evaluated using calibration metrics aligned with the physical flooding processes and decision thresholds being assessed.**

## Issue 3: Insufficient Reporting of Model Performance Metrics

The *Report* identifies several calibration targets, including allowable error thresholds for modeled peak stage, peak discharge, timing of peak, and runoff volume. However, there is limited reporting of objective performance metrics that would enable assessment of model predictive skill and calibration adequacy. While threshold-based calibration criteria are informative, they do not fully characterize

model performance and may obscure systematic bias or poor representation of hydrograph shape. In the absence of quantitative goodness-of-fit metrics, it is difficult to evaluate whether model agreement with observed conditions is statistically robust or whether performance varies substantially among locations and storm types.

Current best practice to evaluate hydrologic and hydraulics (H&H) models generally includes reporting of objective statistics such as Nash–Sutcliffe Efficiency (NSE), root mean square error (RMSE), mean absolute error (MAE), percent bias (PBIAS), peak timing error, and volumetric error (Moriasi et al., 2007). These metrics allow reviewers to distinguish between models that reproduce flood peaks only and models that more comprehensively represent hydrograph timing, magnitude, recession behavior, and water balance. **The Report does not provide these commonly accepted error metrics, diminishing confidence in its results.**

## Issue 4: Insufficiently Fine Spatial Resolution

The *Report* describes a tier-based mesh framework consisting of 500-ft cells in high-priority regions, 1,000-ft cells in medium-priority regions, and 2,000-ft cells in low-priority regions, with localized refinement near channels and hydraulic structures (Figure 3). While this approach is computationally efficient and may be appropriate for broad watershed-scale screening, the selected mesh resolution raises concerns regarding its suitability for detailed pluvial flood representation in urban and suburban environments. The *Report* emphasizes that a principal advantage of the RoM framework is its ability to simulate localized flooding, ponding, and overland flow that may not be represented by traditional fluvial modeling approaches. However, the relatively coarse computational grid may limit the model's ability to resolve the very processes it seeks to characterize.

Pluvial flooding is highly sensitive to microtopography and small-scale hydraulic controls (Bates et al., 2010). Computational cells on the order of hundreds of feet may spatially average these features and smooth important elevation gradients, particularly when derived terrain variability is aggregated within a coarse mesh. As a result, modeled flood pathways, ponding depths, timing of runoff concentration, and inundation connectivity may differ substantially from observed behavior.

This issue is particularly relevant because the *Report's* conclusions seek to attribute changes in flood hazard to future subsidence. Subsidence-driven changes in flood behavior may manifest through relatively subtle alterations in local slope, drainage efficiency, or ponding depth. When computational cells are large relative to local hydraulic controls, small but potentially meaningful changes in topographic gradients may be masked or numerically dampened. Consequently, predicted differences between baseline and future subsidence scenarios may be influenced as much by model resolution limitations as by physical changes in terrain. The concern is not necessarily that the selected mesh invalidates results, but rather that the *Report* provides limited evidence demonstrating that the adopted resolution is sufficiently fine to capture localized flood response with acceptable accuracy.

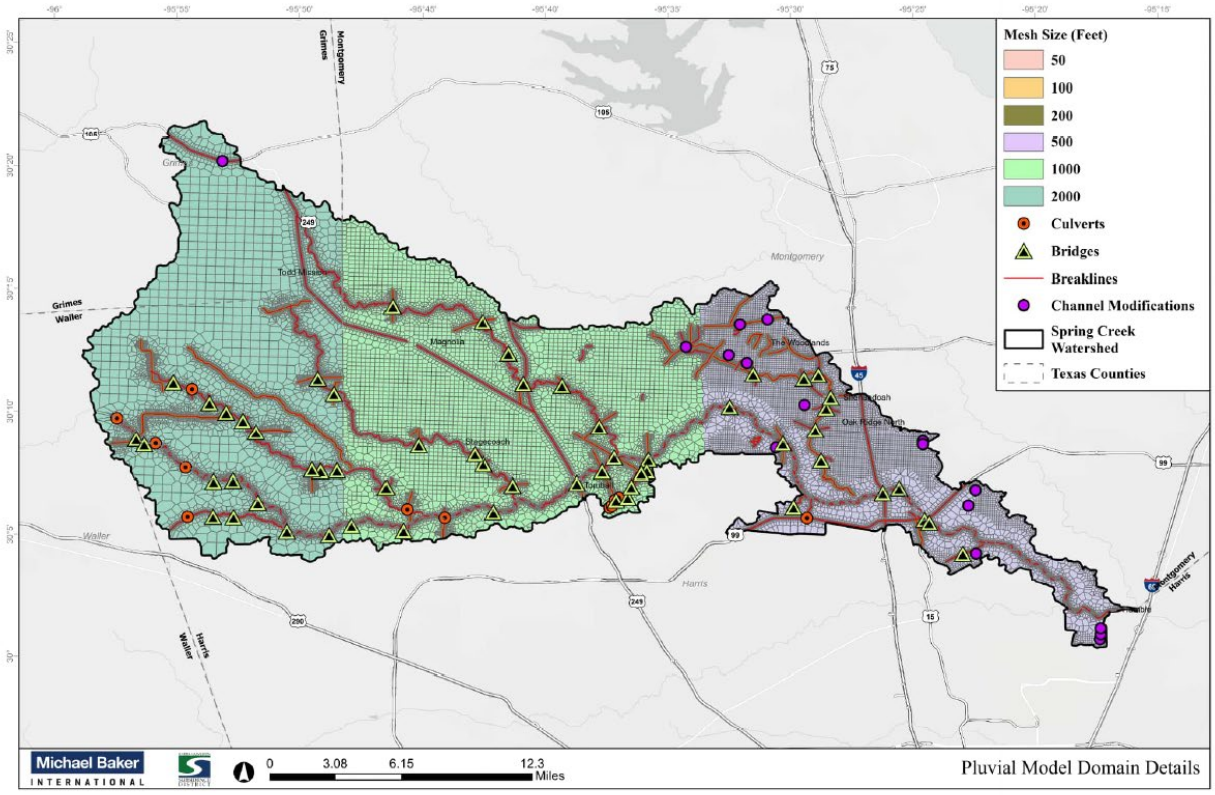



*Figure 3 – Reproduced from Technical Memorandum #2: Appendix B, showing the differences in mesh size between regions*

Although the *Report* documents the selected tier-based mesh configuration and describes refinement around hydraulic controls, this review did not identify evidence of a formal mesh sensitivity analysis or numerical convergence assessment. Because computational mesh resolution is one of the most influential drivers of two-dimensional hydraulic model behavior, evaluation of solution stability under alternative mesh discretization is an important component of technical defensibility. Without demonstrating that modeled inundation patterns remain reasonably consistent under finer or alternative mesh configurations, it is difficult to determine whether predicted differences between baseline and future scenarios represent physical system response or numerical artifacts.

Numerous studies (e.g., Cook and Merwade, 2009; Papaioannou et al., 2016; Steven et al., 2016) demonstrate that coarse grids may underestimate or overestimate flood depths, misrepresent hydraulic connectivity, and alter flood extent through terrain smoothing effects. While no universally "correct" cell size exists, best practice generally involves demonstrating that selected spatial resolution provides stable results for the intended modeling objective and scale of decision-making. **For watershed-scale screening, coarser grids may be defensible; however, stronger justification is warranted when conclusions are interpreted as localized changes in flood hazard attributable to subsidence.**

## Issue 5: Selection of Model Parameter Values Outside Established Ranges

To describe the roughness of the land surface and predict the rate at which water will move through the modeled environment, the model uses "Manning's n" values for all areas within the modeled domain. Larger values of n indicate rougher surfaces, where water will move more slowly downgradient. It is common practice to assign initial n values based on the land use/land cover of an area, using values that are within generally accepted ranges as published in various hydrologic reference material. These initial n values are then modified in order to yield modeled water levels and hydraulic properties that accurately match observed values. The *Report* states that this was their general procedure in developing their HEC-RAS models, and concluded (TM2, pg. 26), "the final Manning's n values were selected (Table 6) which provided results within acceptable limits."

Table 1 presents a comparison of the final Manning's n values from the calibrated model, along with the recommended appropriate range as specified in the HEC-RAS manual. Values are provided for each of the land use categories described by the *Report*, matched to categories listed in the HEC-RAS manual as closely as possible. Red shading indicates that the *Report's* calibrated value is outside of the acceptable range of values listed in the HEC-RAS manual for the same land use type. As shown, 8 out of the 19 land use categories were assigned Manning's n values outside of the acceptable range. In addition, four of the land use categories defined by the Authors were not included as categories in the HEC-RAS manual. Of the seven land use categories with Manning's n values within the acceptable range, three were at the exact upper bound of the range, and one was at the range's lower bound.

*Table 1 – Manning's "n" values used in The Report vs. ranges recommended in the HEC-RAS Manual*

| | **Value of "Manning's n" Parameter** | |
|---|---|---|
| **Land Classification** | **Report** | **HEC-RAS Manual** |
| No Data | 0.035 | |
| Developed – High Intensity | 0.12 | 0.12-0.20 |
| Building | 10 | |
| Developed Low-Intensity | 0.1 | 0.06-0.12 |
| Developed – Open Space | 0.05 | 0.03-0.05 |
| Cultivated Crops | 0.08 | 0.02-0.05 |
| Pasture-Hay | 0.08 | 0.025-0.05 |
| Grassland-Herbaceous | 0.08 | 0.025-0.05 |
| Deciduous Forest | 0.15 | 0.1-0.2 |
| Evergreen Forest | 0.2 | 0.08-0.16 |
| Mixed Forest | 0.2 | 0.08-0.20 |
| Scrub-Shrub | 0.1 | 0.07-0.16 |

| Land Classification | Report | HEC-RAS Manual |
|---|---|---|
| Palustrine Forested Wetland | 0.2 | 0.05-0.085 |
| Palustrine Scrub-Shrub Wetland | 0.2 | 0.05-0.085 |
| Palustrine Emergent Wetlands | 0.2 | 0.05-0.085 |
| Unconsolidated Shore | 0.07 | |
| Barren Land | 0.03 | 0.023-0.030 |
| Open Water | 0.15 | 0.025-0.05 |
| Palustrine Aquatic Bed** | 0.07 | |

**Palustrine wetlands assumed as "Emergent Herbaceous Wetlands" in HEC-RAS manual

The selection of out-of-range Manning's n values caused the model calibration to rely on parameter values that are not consistent with commonly accepted guidance for several land-cover types. While calibration often requires adjustment of Manning's n values, selecting values outside established ranges without supporting justification raises the possibility that these parameters are compensating for other sources of model error, such as deficiencies in terrain representation, boundary conditions, or other calibration parameters. As a result, the calibrated model may reproduce observed water levels while relying on physically unrealistic parameterization, reducing confidence that the model will accurately predict flooding under future conditions different from those used for calibration.

**Without demonstrating why these out-of-range Manning's n values are physically appropriate, confidence in the model's calibration and its predictive capability is reduced.**

## Issue 6: No Scenario Tested the Hydrologic Impacts of Land Development

The Report relies on three modeled scenarios to assess the impact of subsidence and land development on flooding by 2070. They were:

1. Baseline Model
2. Subsidence without Future Land Development (SWFD)
3. Subsidence with Future Land Development (SFD)

A fourth potential scenario, 4. Land Development without Future Subsidence (LDWS), was not considered in the *Report*. Results from a land development scenario, when compared to the Baseline scenario, would demonstrate the degree to which land development alone contributes to the reported rise in flood damage.

Additional flood impacts from future land development can occur in two ways: a) land use/land cover change physically alters the hydrology of a watershed and b) additional buildings and infrastructure result in additional damages. According to the Report:

> *Urban development is expected to significantly increase the number of impervious surfaces, such as new buildings and structures, roads, rooftops, parking lots, etc. This expansion will reduce natural land cover, typically leading to more impervious surfaces, such as roads and buildings. This will lead to decreased infiltration of rainwater into the soil and increased surface runoff, and consequently, urban areas will face higher risks of flooding (TM2, pg. 7).*

The report itself concludes that damages increase by ten-fold when these physical impacts of land development are considered:

> *A 1% AEP flood event in 2070 could result in an additional $43 million in losses due to subsidence alone. When future development and increased impervious cover are considered, this impact rises to $466 million (TM3, pg. 70).*

The impact of the second type, due to the presence of additional people and infrastructure, is treated less rigorously:

> *A caveat to the future development H&H modeling scenario is that it does not consider future development in structures and infrastructure densities, even though the model considers the future increase in flows due to changes land cover. To partially account for this issue, a 9% increase was applied to losses in the SFD scenario. Including these factors, the total projected loss climbs to $560 million (TM3, pg. 70).*

This separation is also important because the system displays non-linear behavior. Subsidence and land development likely interact in a synergistic (additive) manner, so it is unclear if the difference between a baseline and land development scenario would be the same as the difference between the subsidence only and subsidence with land development scenario.

The framing in the conclusions is problematic, particularly with regard to the Executive Summary. The study appears to suggest that if subsidence did not occur, then $560 million in economic losses could be avoided. An alternate, equally plausible, way to frame this is that additional land development could cause up to $517 million in economic impacts. However, without modeling Scenario 4, this number is unknowable. **Thus, inclusion of a "Land Development Only" scenario would have provided a fairer perspective on the scale of impacts due to subsidence, highlighting a potentially ten-fold increase in damages from changes in land cover as compared to those from subsidence. The failure of the Executive Summary to provide loss values for both conditions, with and without future development, is misleading.**

## Issue 7: Uncertainty in Subsidence Values Not Addressed

According to the *Report*, subsidence predictions were based on results produced by the USGS's GULF-2023 model, which at the time was proposed as the new Groundwater Availability Model (GAM) for the region. The model was run with a baseline management scenario showing anticipated

pumping from 2019 through 2070, with extraction rates based on projected population growth and water management strategies implemented by stakeholders. This scenario was not discussed as part of the *Report*; therefore, it is not possible to evaluate its plausibility. However, like all projections of future growth, the results inherently have a high degree of uncertainty.

According to its documentation (Ellis et al., 2023), the GULF-2023 model itself also has inherent structural uncertainty associated with its subsidence predictions, as is the case with any groundwater model. When compared with existing extensometer data, which is accurate to within millimeters (e.g. Wang et al., 2014; Gambolati & Teatini, 2021), the model underpredicts the measured compaction values by 0.3 ft on average. These differences ranged from an overprediction of 1.4 ft to an underprediction of 0.2 ft. (Figure 4). This residual is similar to the benchmark observations, which underpredicted subsidence by 0.2 ft but had a residual range of 2 ft over to 3.5 ft under. Accuracy varied by location; according to the report, "Subsidence was slightly undersimulated in northern Harris County as a result of oversimulated groundwater levels in the Evangeline and Jasper aquifers. Simulated subsidence was similar to observed and estimated values of subsidence at the Woodlands at benchmarks T 88 and U 88 [Figure 5] (Ellis et al., 2023)."

It should also be noted that since the original Report was published, the TWDB has approved a new GAM for Groundwater Management Area 14 (GMA-14; Keester et al., 2025), which adjusts pumping rates, hydraulic properties, and material compaction parameters relative to GULF-2023. These updates improved the average residual, which now shows a 0.03 ft difference and no bias towards under or over prediction (Figure 6). If the modeling conducted in the Spring Creek Report is revisited, it should use the newer model (Keester et al., 2025).

The primary issue with the *Report* is that it does not address the potential impacts of this uncertainty in its predictions. Similar to what was noted in Issue 2, a small error in predicted subsidence could induce a large error in flood inundation extents. Given that the *Report* claims that an inch change in land subsidence, averaged over the watershed, results in $32 million in damages, a 0.3 ft error in subsidence could result in a $115 million error in assessing impacts. **An uncertainty analysis of how the groundwater modeling parameters and pumping scenarios influence subsidence predictions is necessary to support the Report's conclusions.**

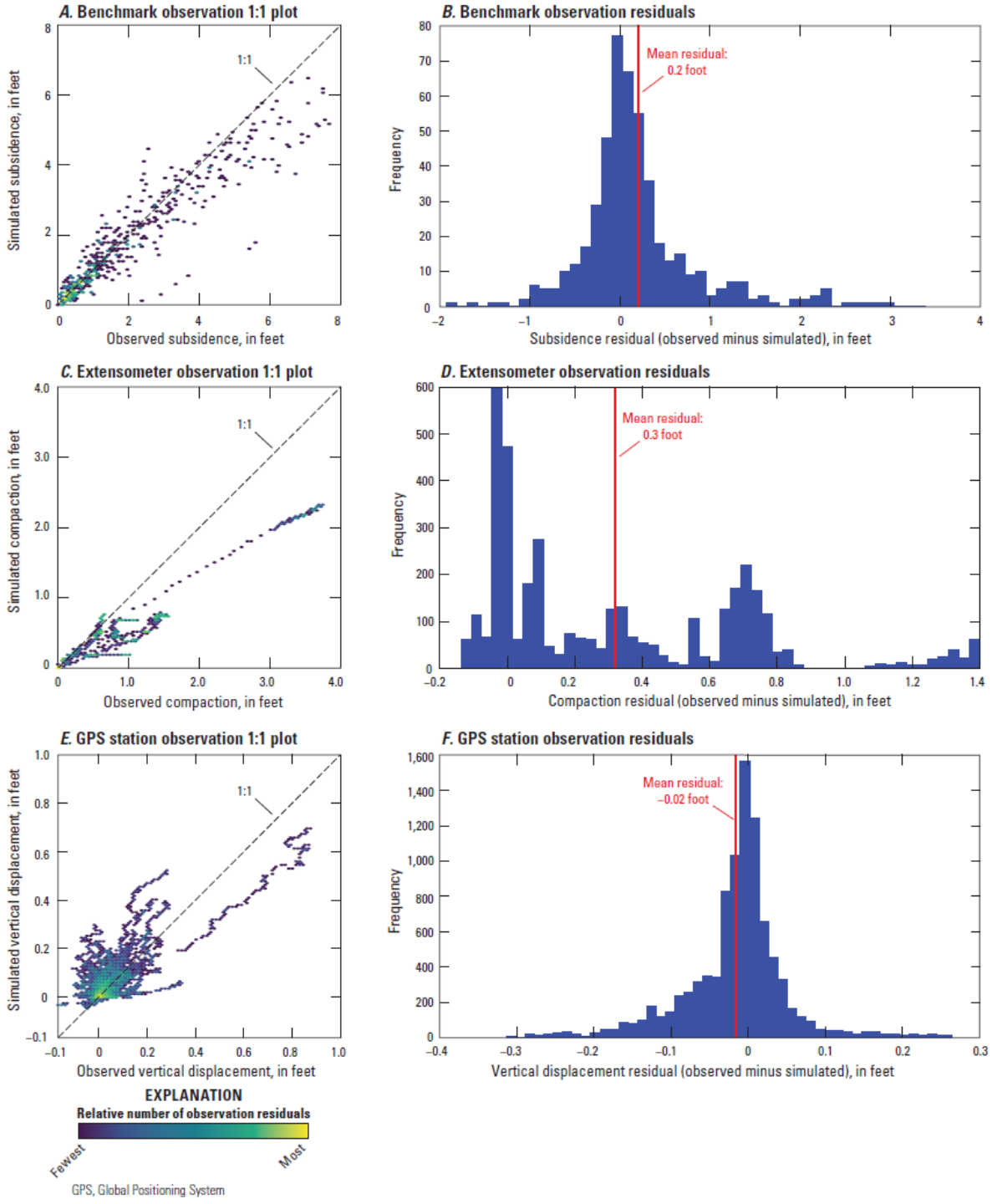
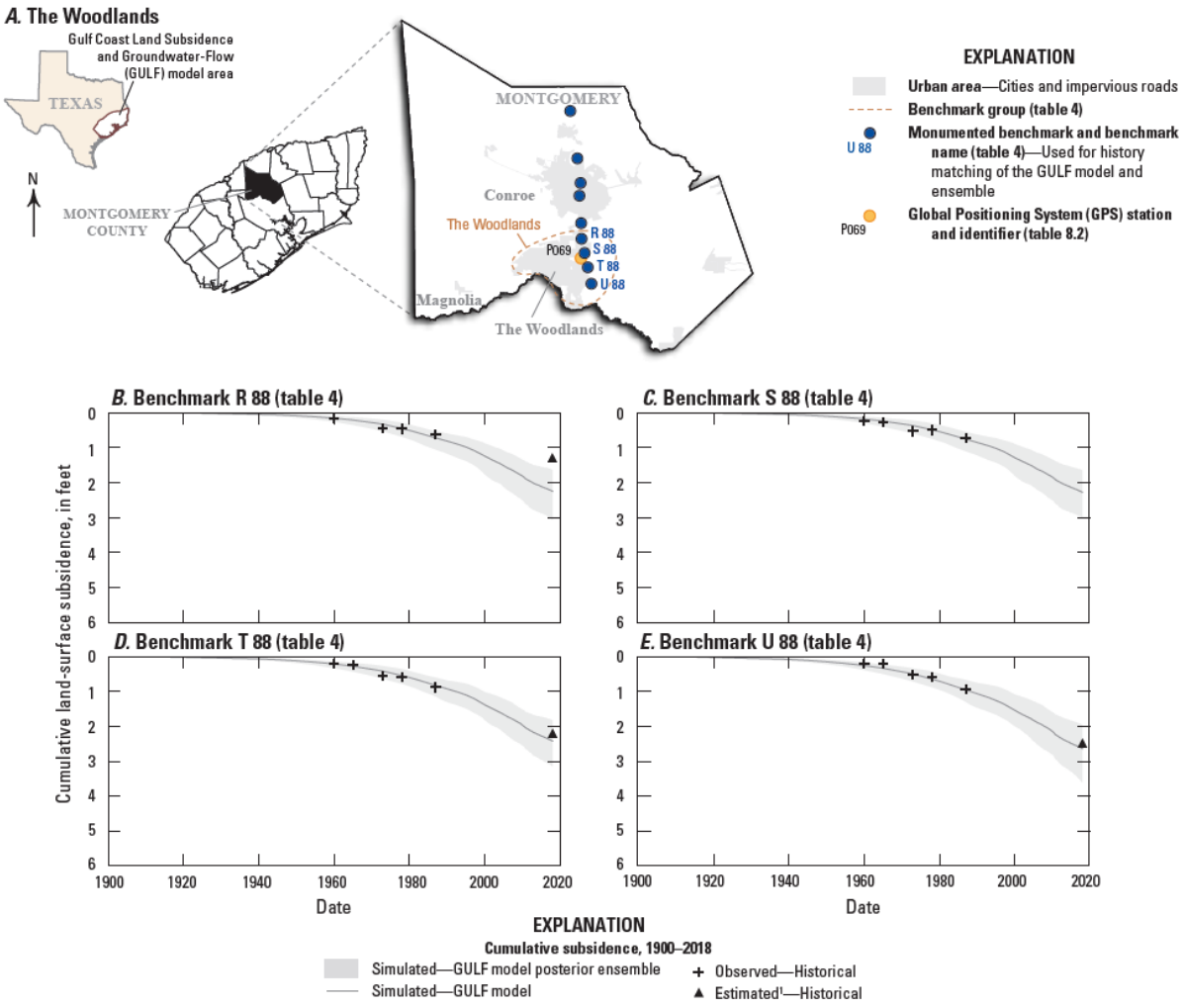



*Figure 4 – Reproduced from the GULF-2023 Model, showing error*




[1]The estimated subsidence through 2018 at benchmarks R 88, T 88, and U 88 was calculated based on the methods described in table 9 using vertical-displacement data from GPS station P069.

| Benchmark group | Benchmark (fig. 70A) | County | GULF-model-simulated hydrogeologic unit compaction in 2018, in feet | | | | GULF-model-simulated land-surface subsidence through 2018, in feet (figs. 172–174) | Estimated land-surface subsidence through 2018, in feet[1] | Observed or estimated land-surface subsidence through 2021, in feet (fig. 96; table 4) | GULF-model-simulated hydrogeologic unit compaction as a percentage of simulated land-surface subsidence[3] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Layer 2 (Chicot aquifer) | Layer 3 (Evangeline aquifer) | Layer 4 (Burkeville confining unit) | Layer 5 (Jasper aquifer) | | | | Layer 2 (Chicot aquifer) | Layer 3 (Evangeline aquifer) | Layer 4 (Burkeville confining unit) | Layer 5 (Jasper aquifer) |
| Conroe (fig. 174) | K 88 | Montgomery | 0.01 | 0.6 | 0.03 | 1.2 | 1.8 | 1.2 | [2]1.2 | 0.6 | 33 | 1.7 | 67 |
| | CONROE RM 1 | Montgomery | 0.02 | 0.8 | 0.04 | 1.2 | 2.1 | 1.4 | 1.5 | 1.0 | 38 | 1.9 | 57 |
| | Q 88 | Montgomery | 0.05 | 1.2 | 0.05 | 0.9 | 2.2 | 1.3 | [2]1.4 | 2.3 | 55 | 2.3 | 41 |
| The Woodlands (fig. 173) | R 88 | Montgomery | 0.08 | 1.3 | 0.05 | 0.8 | 2.2 | 1.3 | [2]1.3 | 3.6 | 59 | 2.3 | 36 |
| | T 88 | Montgomery | 0.1 | 1.4 | 0.07 | 0.8 | 2.4 | 2.2 | 2.2 | 4.2 | 58 | 2.9 | 33 |
| | U 88 | Montgomery | 0.1 | 1.5 | 0.07 | 0.9 | 2.6 | 2.5 | [2]2.5 | 3.8 | 58 | 2.7 | 35 |
| Northern Harris County (fig. 172) | SPRING RM 1 | Harris | 0.5 | 2.0 | 0.08 | 0.5 | 3.1 | 3.9 | 4.2 | 16 | 65 | 2.6 | 16 |
| | V 660 | Harris | 1.4 | 2.7 | 0.09 | 0.2 | 4.4 | 5.1 | 5.2 | 32 | 61 | 2.0 | 4.5 |

[1]Land-surface subsidence through 2018 was estimated by (1) multiplying the difference of the vertical displacement through 2019 and through 2020 at the closest GPS station (fig. 76; table 6) by 2 to account for the period 2018–20, then (2) differencing the subsidence through 2020–21 at the benchmark (table 4) and the value from (1).

[2]Not included in figure 96.

[3]Percentages may not sum to 100 because of rounding differences.

*Figure 5 – Table and figure reproduced from the GULF-2023 Model, showing comparison between simulated, estimated, and observed land subsidence (highlights added to show data from sensors in or near the Spring Creek Watershed)*

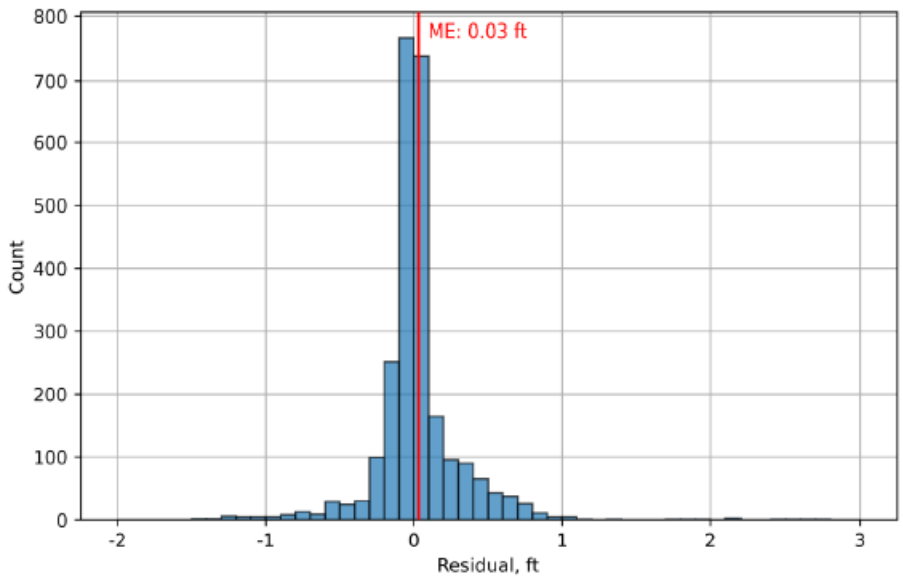



*Figure 6 – Figure reproduced from GMA-14 GAM, showing improved residual values for compaction and subsidence targets*

## Summary

The issues cited above strongly call into question the *Report*'s main conclusion that subsidence alone in the Spring Creek watershed will potentially cause more than $560 million in economic impacts should another 100-year flood event occur by 2070. The veracity of the model is questionable, given technical problems with parameter selection, calibration robustness, grid resolution, and error reporting.

Further, even assuming the model is correct, the conclusions and interpretation are problematic. While a non-trivial fraction of these projected costs (up to $560 million) could reasonably be attributed to subsidence alone, the modeling suggests that much of this is instead due to the alteration of the watershed due to the dramatic land use/land cover changes predicted to occur. For completeness, the *Report* should clearly model and discuss the potential economic impacts associated with land development.

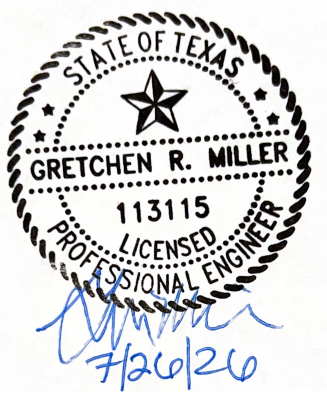
We recommend these issues be resolved by revising the HEC-RAS model parameters and the subsidence values taken from the GAM, recalibrating it based on an improved set of error metrics and storm event data, and adding a model run evaluating Scenario 4. Once the new model results are generated, the economic impact assessment may be re-run and re-analyzed to produce much higher confidence in its results.

## About the Reviewers

Dr. Gretchen Miller, Ph.D., P.E., P.G. is an experienced engineer and hydrogeologist who has been working in the groundwater field for over 20 years. During that time, she has had roles in both academia and environmental consulting. She is currently serving as manager of the South-Central Water Resources Department for Spheros Environmental (formerly known as LRE Water), where her responsibilities include operations and project management, business development, and mentoring junior professionals. Dr. Miller previously served on the Scientific Advisory Committee for the Regional Groundwater Science Partnership regarding subsidence in Harris and Montgomery counties, led by the Houston Advanced Research Center (HARC). She also led a pilot study examining managed aquifer recharge of stormwater within Spring Creek. Dr. Miller was responsible for the revision and finalization of this document.

Amir Sedaghatdoost, Ph.D., is a water resources engineer with Spheros Environmental. He has over seven years of experience in academia and environmental consulting, specializing in hydrologic, hydraulic, groundwater, and water quality modeling. His expertise includes the development, application, and evaluation of numerical models, and environmental data assessment to support water resources planning and management. Dr. Sedaghatdoost has worked on studies involving groundwater, reservoir, riverine, and watershed systems. He assisted with the technical review and supporting analyses for this document.

Jordan Furnans, Ph.D., P.E., P.G. is the Principal Engineer and Hydrogeologist at his firm, Windward Water Resources Engineering and Geoscience. His 24 years of professional experience encompasses both field hydrologic data collection and analysis of data through the development and application of numerical models. He has developed many models for predicting hydrologic impacts, including developing floodplain and flooding models using HEC-RAS. He recently served as the hydrology and hydraulics expert as part of the independent external peer review (IEPR) panel charged with reviewing a confidential project by the US Army Corps of Engineers. He is also a lecturer/adjunct faculty member in the Civil, Architectural, and Environmental Engineering department at The University of Texas at Austin, where he teaches undergraduate courses in hydraulics and hydrology. Prior to April 2026, Dr. Furnans served as Principal Engineer for Spheros Environmental and led the initial development of this document.

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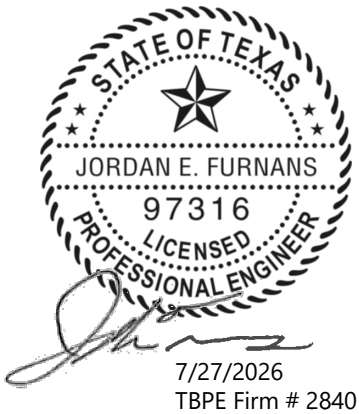


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