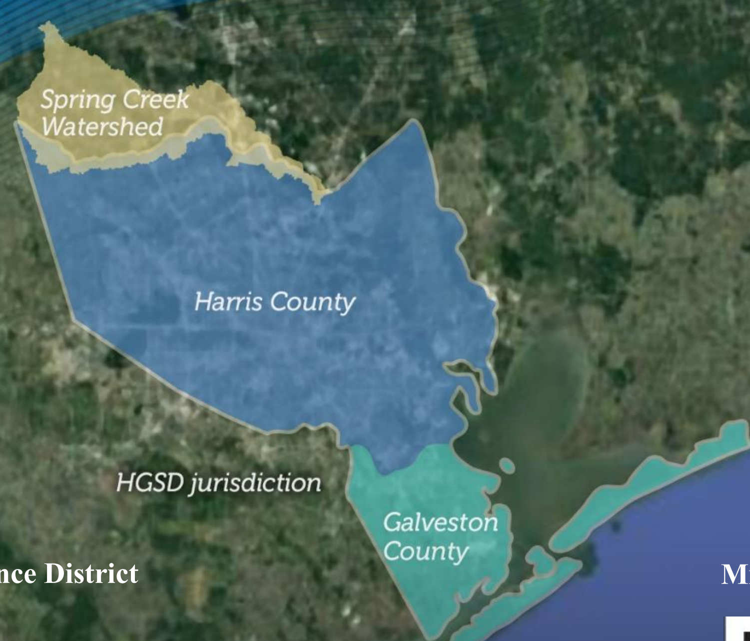
Evaluation of Subsidence Impacts in the Spring Creek Watershed

Technical Memorandum #1: Methodology for Subsidence Grid Development



Submitted to:

Harris-Galveston Subsidence District

HARRIS-GALVESTON SUBSIDENCE DISTRICT

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9/10/2025
Expires 12/31/2025

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Abbreviations/ Acronyms

DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Global Positioning System
GULF	Gulf Coast Land Subsidence and Groundwater-Flow model
H&H	Hydrology and Hydraulics
HCFCD	Harris County Flood Control District
HEC-RAS	Hydrological Engineering Centre – River Analysis System
HGSD	Harris-Galveston Subsidence District
IDW	Inverse Distance Weighted
InSAR	Interferometric Synthetic Aperture Radar
LiDAR	Light Detection and Ranging
MBI	Michael Baker International
NSI	National Structure Inventory
RMSE	Root Mean Square Error
USACE	United States Army Corps of Engineers

1.0 Introduction

Michael Baker International (MBI) is evaluating the impacts of future subsidence in the Spring Creek watershed for the Harris-Galveston Subsidence District (HGSD). The project aims to quantify flood risk and economic impacts attributable to current and future subsidence in the Spring Creek watershed and to provide insights on subsidence impacts from non-coastal flooding.

1.1 Purpose of Technical Memorandum 1 (Tech Memo 1)

Tech Memo 1 summarizes the following methodology:

(a) Interpolating the subsidence grids predicted from the Gulf Coast Land Subsidence and Groundwater-Flow (GULF) model.

(b) Incorporating the subsidence grid in the subbasin hydrology and channel bathymetry.

(c) Modifying the hydraulic structures (Bridges, Culverts, and Inline Structures).

(d) Modifying the finished floor elevation or slab deck elevation of buildings.

2.0 Subsidence Grid Interpolation Methodology

2.1 Subsidence Grid Development

Subsidence is the lowering of the land surface elevation due to subsurface movement. Subsidence can be projected using groundwater models, which is the method used in this study for the development of a future subsidence grid. A raster grid was generated to estimate the cumulative subsidence from 2019 through 2070. This subsidence grid covers the predictive portion of a baseline scenario extracted from HGSD's Joint Regulatory Plan Review (Technical Memorandum Joint Regulatory Plan Review Model Scenario Documentation). The baseline scenario utilizes projected population growth, coupled with water management strategies from major water providers, to estimate groundwater demand. This demand is then applied to a regional GULF model to predict aquifer and land subsidence impacts. The GULF model was calibrated with land surface elevation data from the late 1890s to 2018[1]. This period was selected as it aligns with the Light Detection and Ranging (LiDAR) acquired in 2018, which is used in the digital elevation model (DEM) within the HCFCD model. Therefore, both models (i.e., GULF and Spring Creek Watershed Model) contain land elevation data from 2018 and serve as the starting point for future projections. The subsidence grid was used to modify the DEM within the HCFCD model to account for total future subsidence in 2070, incorporating an annual time step from 2019 to 2070.

The subsidence grid from HGSD was provided in a raster format in the resolution of 1 kilometer x 1 kilometer (0.62 miles x 0.62 miles), which covered the entire Spring Creek and Willow Creek watersheds (**Figure 1**). The available hydraulic model terrain used in the HCFCD model has a much finer resolution: 3 feet x 3 feet. Hence, to create the subsided terrain for the year 2070, the subsidence grid was proposed to be interpolated to the same resolution as that of HCFCD LiDAR resolution (3 feet x 3 feet) using interpolation. There are several interpolation techniques available; each has its advantages and disadvantages. The following sections describe some of the available techniques for interpolation methodologies.

[1] https://doi.org/10.3133/pp1877

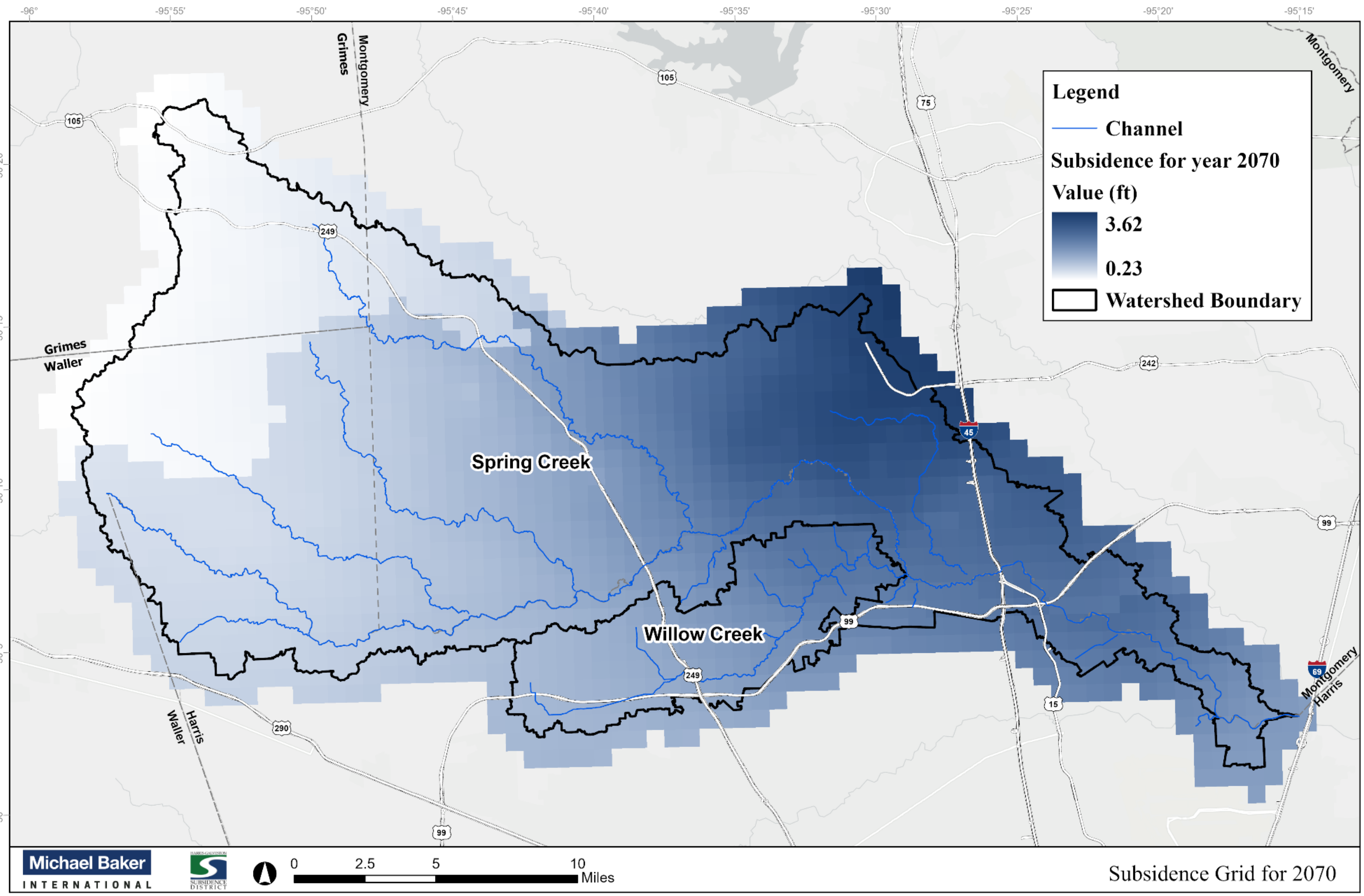

Figure 1 – Total Projected Subsidence from 2018-2070 Using the Baseline Scenario from HGSD's Joint Regulatory Plan Review

2.2 Bilinear Interpolation and Cubic Convolution

Bilinear interpolation uses the value of the four nearest gridded points to determine the value of the raster cell. The new value for the raster cell is a weighted average of these four gridded points, adjusted to account for their distance from the center of the raster cell. **Figure 2** shows an example of bilinear interpolation[2]. The red point is the cell center, and the orange points are the four nearby selected gridded points. The cell shaded in yellow is the output cell value of the raster, which represents the weighted average of the four points.

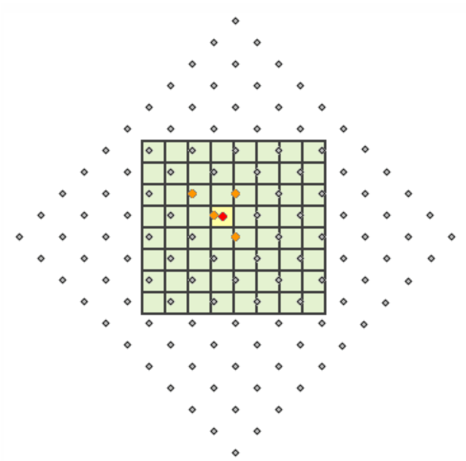

Figure 2 – Bilinear Interpolation Example Showing Weighted Average (Red) Point being Calculated from Neighboring Four (Orange) Points

Similar to bilinear interpolation, cubic convolution[2] uses 16 nearby values from the gridded points to calculate the weighted average. **Figure 3** shows an example of interpolation using cubic convolution. The 16 selected orange points are used to calculate the weighted average of the raster cell value (red orange point).

[2] https://desktop.arcgis.com/en/arcmap/latest/extensions/spatial-analyst/performing-analysis/cell-size-and-resampling-in-analysis.htm

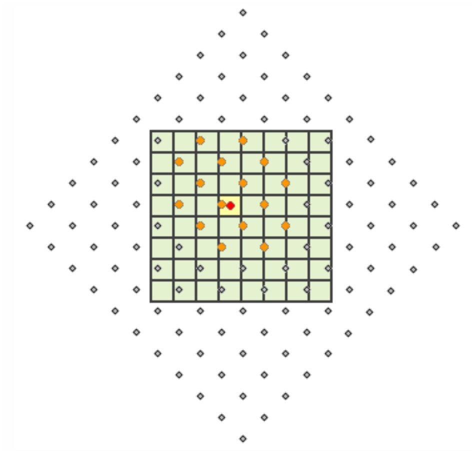

Figure 3 – Cubic Convolution Interpolation Example Showing Weighted Average (Red) Point being Calculated from Neighboring 16 (Orange) Points

2.3 Inverse Distance Weighted

Inverse Distance Weighted (IDW)[3] interpolation determines cell values using a linearly weighted combination of sample points. The weight is a function of inverse distance, i.e., the greater the distance, the less influence the point has on the output value. **Figure 4** shows the weights assigned to each data point that is used to generate a predicted value at the location marked by the crosshair. Points near the raster cell are given more weight than points farther away.

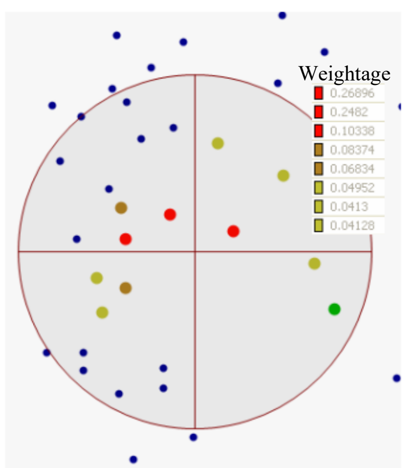

Figure 4 –IDW Interpolation Example Showing Weighted Average at the Crosshair being Calculated with Higher Weightage from near (Red) Points.

Notes: The point at the crosshair is being calculated using all the points shown, however the value of the interpolated point at the crosshair will be dependent more due to the neighboring red point (higher weightage value shown in legend) and will gradually decrease on the distant points the distance of points from the one that is being interpolated increases.

[3] https://pro.arcgis.com/en/pro-app/latest/help/analysis/geostatistical-analyst/how-inverse-distance-weighted-interpolation-works.htm

The IDW interpolation relies on the inverse of the distance raised to a mathematical power. This exponent controls the significance of surrounding points on the interpolated value. Higher power results in less influence from distant points. It can be any real number greater than 0, but commonly used ranges from 0.5 to 3. **Figure 5** shows an example of how the weights for the points decrease with distance and the exponent; a higher value (p=2) gets less influence from distant points, while a lower value (p=1) gets comparatively more influence from distant points, while a zero exponent shows the influence does not change with the distance.

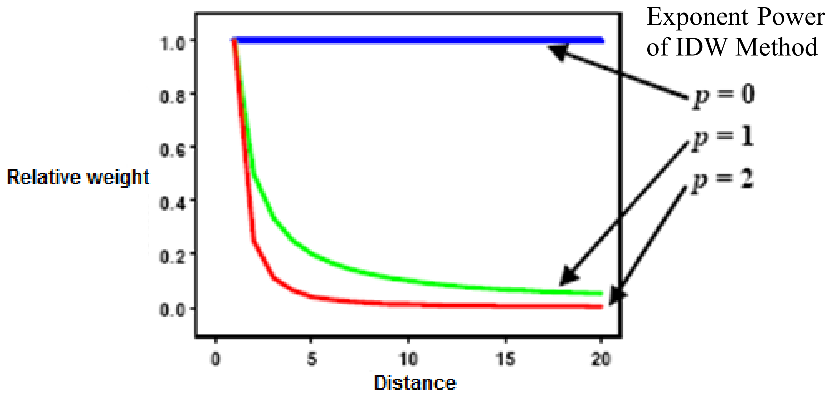

Figure 5 – IDW Interpolation Example Showing Reducing Weight of the Sampled Points with Distance from the Interpolated Point and Exponent Power (p)

Notes: The value of the interpolated point at the crosshair (from Figure 4) depends on the weighted sampled points based on the exponent power (p) used in the IDW method. A value of p=0 (zero, color=blue) means the IDW method does not account for the distance of the sampled points from the interpolated point, while as the value of p increases, the IDW accounts for a low weightage of the distant point. For example, in the Figure 5 above, a higher value (p=2) gets less influence from distant points, while a lower value (p=1) gets comparatively more influence from distant points.

2.4 Ordinary Kriging

Ordinary kriging is a spatial interpolation method that estimates values at specific locations within a continuous spatial field. It uses a limited set of sampled data points to interpolate values based on the spatial correlation between these points. Unlike other simpler methods (such as Bilinear or Cubic interpolation), ordinary kriging considers the empirical observations' spatial arrangement rather than relying on a predefined model of spatial distribution. It also provides uncertainty estimates for each interpolated value, assuming the model as follows:

$$Z(s) = \mu + \in (s)$$

where, $Z(s)$ is the predicted term in a location (s), μ is an unknown constant and $\in (s)$ is a spatially variable error term.

The kriging weights prioritize nearby points and account for clustering, reducing bias in predictions. This process involves determining the spatial covariance structure using a variogram and then using weights derived from this structure to interpolate values for unsampled points across the field. **Figure 6** illustrates an example in one spatial dimension.

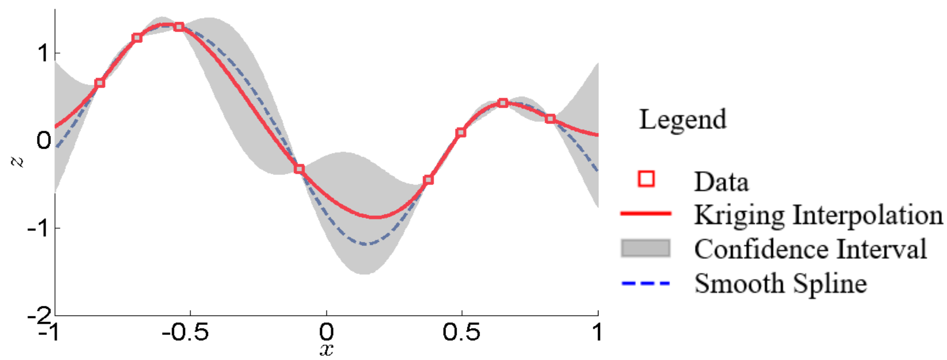

Figure 6 – Example of kriging in one spatial dimension with data (red square), its Kriging interpolation (red line) with confidence interval (gray shade), and smoothed spline interpolation (blue dash)

In **Figure 6**, the squares indicate the data. The dashed curve shows a spline, which is the true, unknown mean (μ). The mean is smooth but departs significantly from the expected values given by those means. The difference, $\in(s)$ is a function of the model spatial distribution and the kriging interpolation, $Z(s)$, shown in red, runs along the means of the normally distributed confidence intervals, shown in gray, produced by kriging variance. The model estimated $Z(s)$ remains within the limit of the variogram (gray).

3.0 Subsided Terrain

The ultimate goal of grid interpolation is to develop a seamless topographic surface that estimates the subsidence grid in the same resolution as the terrain used in the HCFCD model. Once the subsidence grid is developed for future groundwater use, it can be used to subside LiDAR-based ground surface/terrain inherent within the HCFCD models.

All the approaches described in Sections **2.2, 2.3,** and **2.4** were used to interpolate a subsidence raster of 3 feet x 3 feet resolution for the Spring Creek watershed in 2070. They were subtracted from the existing terrain to calculate the subsided future terrains, which is also called mosaicking of the rasters. Another terrain was also developed where no interpolation was applied, and the original 1-kilometer x 1-kilometer subsidence data were directly subtracted from the existing terrain to calculate the corresponding subsided terrain. **Figure 7** compares different interpolation methods near Grand Parkway Road within the Spring Creek watershed.

Figure 7 shows four interpolation methods that match closely. This is because the input subsidence grid data used has a resolution of 1 kilometer x 1 kilometer, whereas the interpolated results were 3 feet x 3 feet. Hence selection of any of the four interpolation methods did not produce a significant difference in the output of the interpolated surface. However, the Kriging interpolation method is more robust because it accounts for spatial correlation between data points, using the variogram and covariance functions[4]. It is also more robust to outliers. Hence, the Kriging method is selected for the interpolation of original subsidence grid data from 1 kilometer x 1 kilometer to 3 feet x 3 feet resolution for this study.

The subsided terrain will be further used to update the hydrologic and hydraulic (H&H) parameters, such as subbasin slope, channel slope, elevation of hydraulic structures, building footprint, etc.

Figure 8 (A) shows the subsided terrain of 2070 while **Figure 8 (B)** shows the cross-sections at selected locations in the watershed showing existing (2018) and subsided (2070) terrain created using an interpolated subsidence grid using the Kriging method.

[4] Statistical Inverse Distance.doc (ccgalberta.com)

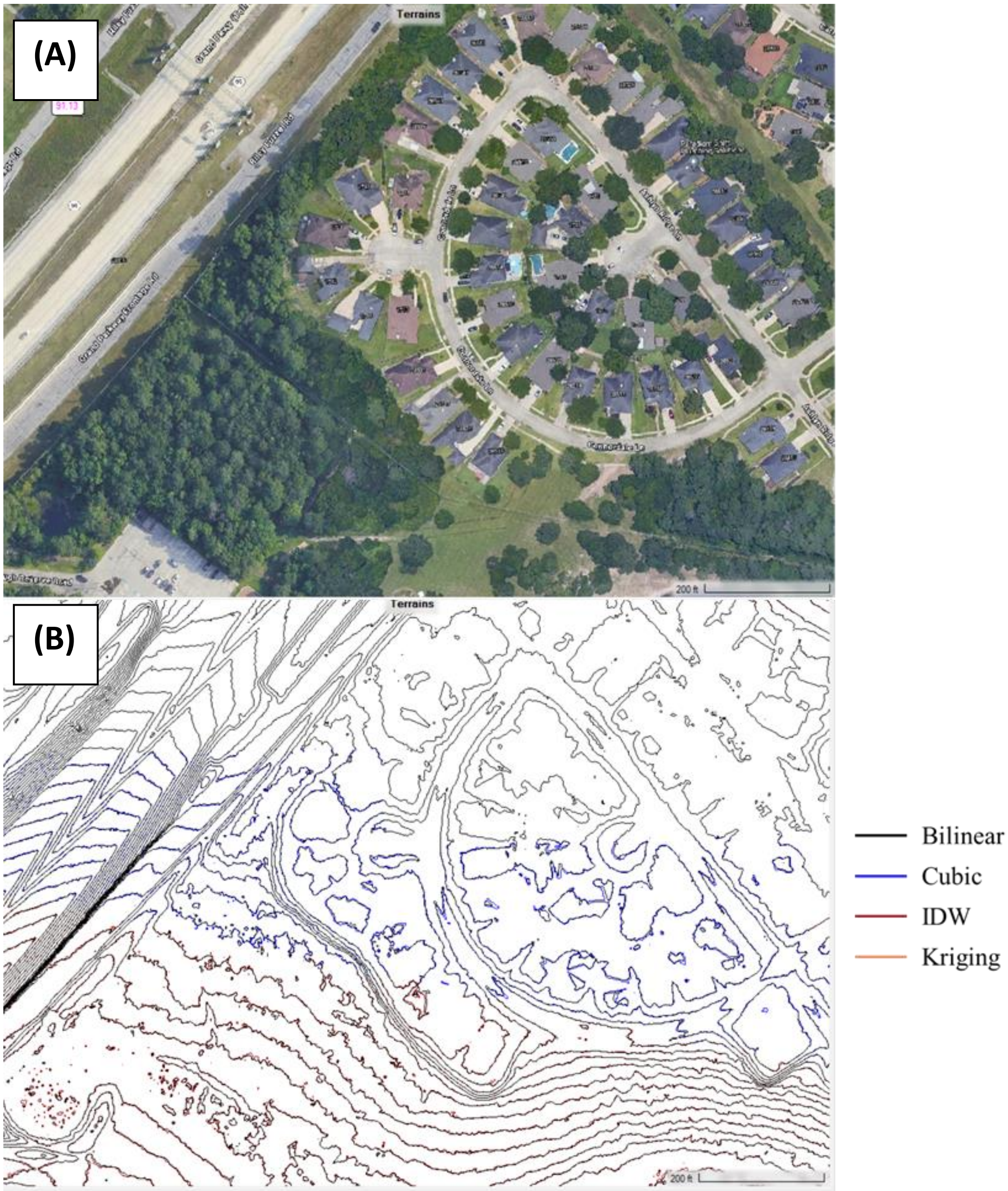

Figure 7 – (A) Grand Parkway Road within the Spring Creek watershed; example location with imagery from Google Earth, extracted in July 2024. (B) A comparison of different interpolation method results for the same extent is shown in (A).

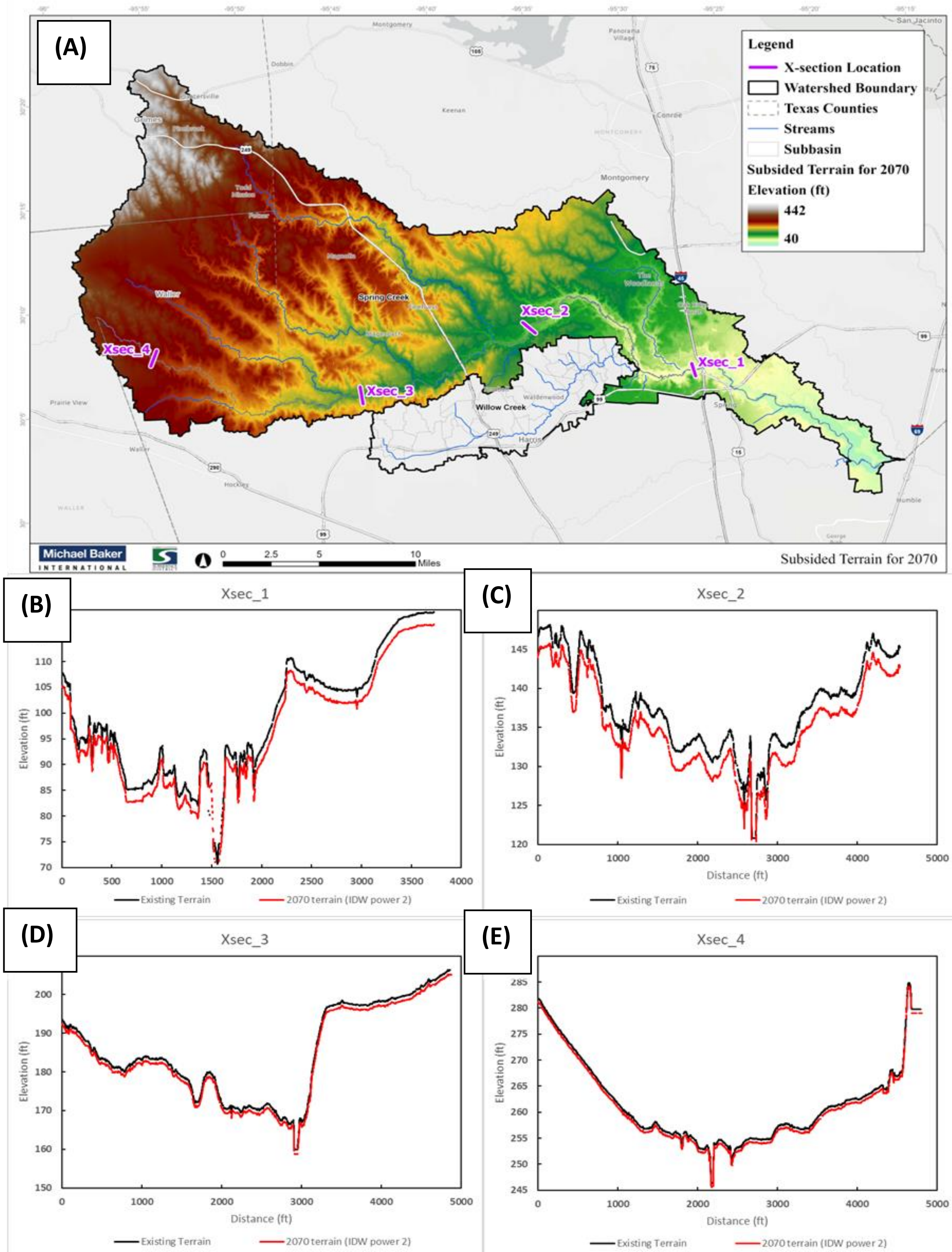

Figure 8 – (A) Subsided terrain of Spring Creek for the year 2070 using the baseline scenario from HGSD's Joint Regulatory Plan Review. (B) to (E) Four different x-section locations along the Spring Creek main channel were picked for comparison between 2020 and 2070 terrain and are shown in subfigures

3.1 Modification of subbasin hydrology and channel bathymetry

The existing terrain was extracted from the HCFCD models, which included channel bathymetry. Therefore, subsiding the terrain will also subside the channel bathymetry, creating a single raster surface.

The average slopes of the subbasin used in the calculation of the Time of Concentration & Storage Coefficient were recalculated using the subsided terrain dataset using the zonal statistics tool in ArcGIS. The channel slope was recalculated from the subsided terrain using the stream centerline shapefile. The slopes were calculated based on the HCFCD model slope calculation spreadsheet, which was included with models as part of the model-support data. The recalculated slopes (both subbasin slopes and channel slopes) were used to modify the Time of Concentration and Storage Coefficient values that will update the hydrological model for the subsidence scenario.

3.2 Modification of the Hydraulic Structures

Hydraulic structures such as bridges, culverts, and inline structures (gates, spillways, weirs, etc.) were modified to account for the change in ground elevation due to subsidence. Based on the subsided terrain, the deck elevations, piers, aprons, inverts, etc. of each structure were lowered in the Hydrological Engineering Centre – River Analysis System (HEC-RAS) model to match the change in elevation of the subsidence scenario. An updated hydraulic HEC-RAS model was created based on the calculated subsided surface.

3.3 Evaluation of Subsidence for Building Footprints

The National Structure Inventory (NSI) from the United States Army Corps of Engineers (USACE), which covers the four counties (Harris, Montgomery, Waller, and Grimes) located in the Spring Creek watersheds, will be used for this analysis. Only the structural inventory dataset for Harris County was available from the Harris County Flood Control District (HCFCD). However, the structural inventory dataset for other counties, like Montgomery, Waller, and Grimes counties, was not readily available. Hence NSI dataset was used for four counties for consistency.

The NSI dataset includes attributes for ground elevation and foundation height, which can be used to estimate finish floor elevation for each insurable structure within the watershed. For consistency, the NSI ground floor elevation was updated using 2018 LiDAR terrain for existing conditions. For the subsidence scenario, the ground floor elevation was extracted using the 2070 subsided terrain. The ground elevation for each building footprint was extracted from the terrain using the 'Zonal Statistics as Table' tool in ArcGIS Pro. The tool extracts the average elevation of a building footprint, and these elevations are linked (joined) to each building footprint polygon to represent the building's grade.

4.0 Conclusion

A methodology was developed to process a terrain/topographic surface by interpolating gridded points for future subsidence projection. Four interpolation methods (Bilinear, Cubic Convolution, IDW 2, and Kriging) were assessed for the development of a mosaiced surface using the 2018 LiDAR and 2070 subsidence grid. No interpolation was also assessed for the development of a mosaiced surface. Four interpolation methods, along with the no-interpolation method, match closely for the creation of a mosaiced surface due to the coarse resolution of input subsidence grid data (1 kilometer x 1 kilometer) to produce the interpolated results of 3 feet x 3 feet resolution data. Hence, selection of any of the four interpolation methods did not produce a significant difference in the output of the interpolated surface; however, the Kriging interpolation method was selected as the most robust method out of the four tested methods.

The subsided terrain was further used to modify the H&H parameters, such as hydraulic structures, building elevations, etc. The hydrological parameters, such as subbasin slope and channel slopes, were also recalculated using the subsided terrain individually. The hydraulic structures, such as bridges, culverts, and inline structures, were modified in the HEC-RAS by lowering the deck to match the change in elevation due to subsidence. The ground elevation of the subsided structural inventory dataset was also estimated from the subsided terrains.