Final: Application of Geostatistical Techniques to Quantify Changes in Water Levels

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APPENDIX D
SENSITIVITY ANALYSIS

D.1 Alternative Water Level Maps

The authors are unaware of any previous application of the smoothed simulated water levels and Kriged residuals (SSWL+KR) method for interpolating measured water levels. Because of the SSWL+KR method has not been used in Texas prior to this study, the method was compared to several alternative methods for constructing water level maps in order to investigate the sensitivity of the results to changes in the method's implementation and to compare the results produced by alternative methods. These alternative methods are listed in **Table D-1**.

Table D-1 Methods used to Generate Water Level Maps other than the SSWL+KR Method

Method		Reason for Consideration / (How it was Implemented)
#	Name /(Alias)	
1	Simulated smoothed WLs + Kriged residuals (SSWL+KR)	• Considered Best Science Available • (Detrended annual measured WLs using smoothed GAM simulated WLs for each year and Kriged the residuals)
2	Simulated smoothed 2000 WLs + Kriged residuals (SSWL2000+KR)	• Evaluate the sensitivity trend selection • (Same as SSWL+KR but used the GAM simulated 2000 WLs to detrend all measured WLs from 2000 to 2020)
3	Simulated WLs + Kriged WLs residuals (SWLs+KR)	• Evaluate sensitivity of using smoothed or actual the GAM simulated WLs • (Same as SSWL+KR but GAM simulated WLs were not smoothed)
4	Kriged Measured WLs (KWL)	• Evaluate sensitivity of detrending and not detrending WLs • (Kriged measured water levels using ordinary Kriging)
5	Smoothed Simulated WLs from GAM (GAM_SSWL)	• Determine the results from the trend surface used in SSWL+KR and to determine the impact of smoothing on the trend in the GAM simulated WLs • (Only account for the trend surface; do not consider the Kriged residuals)
6	Simulated WLs from GAM (GAM_SWL)	• Determine the results from the GAM simulation • (Linearly interpolated GAM results from 1 mile to 1000 ft resolution)

Like the SSWL+KR method, methods #2 (SSWL2000+KR) and #3 (SWLs+KR) involve detrending and semivariogram analyses of water levels residuals. In practice, methods #2 and #3 are variants of method #1 and therefore serve as a type of sensitivity analysis for method #1 (SSWL+KR). **Figures D-1** and **D-2** provide examples of the experimental and theoretical semivariograms for Chicot and Evangeline aquifers for 2000, 2013, and 2020 for methods #2 and #3. The spherical theoretical model provided a relatively good fit through to the data and the values for the range are similar to those obtained for method #1 (SSWL+KR). Analysis of the residuals indicates that their distribution approximates a normal distribution. As a result, the application of methods #2 and #3 are technically justified. Method #4 (KWL) does not involve any detrending of the water levels, so Kriging is performed directly on the measured water levels, which are known to contain trends. As a result, the underlying assumptions for ordinary Kriging are not fully met. Nonetheless, the method #4 is presented because it provides useful information regarding whether or not detrending affects the final map of water levels. The impact of ignoring the trend with method #4 (KWL) is evident in the semivariogram analysis for the measured

water levels in Chicot Aquifer in **Figure D-3**. That is, despite fitting a spherical variogram model to the experiment variogram, the portion of the theoretical variogram shown in the plots is nearly linear. The line is a result of the trend in the data, which cause the semivariance to continual increase with an increase in the distance between two data points. Method #5 (GAM_SWL) and Method #6 (GAM_SSWL) use simulated water levels values from the GAM. Results from these two methods are provided primarily for reference.

Figure D-4 compares the 2015 water level contours generated for the Chicot Aquifer by the six methods. All six images provide similar patterns to the contours. **Figure D-5** compares the 2015 water level contours generated for the Evangeline Aquifer by the six methods. All six images provide similar patterns to the contours. In both Figures D-1 and D-2, the plots with contours that have the most bends and irregularities are for methods #5 (GAM_SSWL) and #6 (GAM_SWL), which are the only two methods that incorporate the GAM simulated water levels without any smoothing. The water level contours with the least bends and irregularities occur in the plots for methods #1 (SSWL+KR), #2 (SSWL2000+KR) and #3 (SWLs+KR), all three of which that incorporate the GAM smooth simulated water levels; and the plots with contours with the moderate bends and irregularities are for the method #4 (KWL) that incorporates the Kriged water levels.

D.2 Sensitivity of Annual Change in Water Levels

Figures D-6 through **D-9** provide the change in average annual water levels measurements for the Chicot Aquifer, Evangeline Aquifer, and the Chicot & Evangeline Aquifer from 2000 to 2020 for Calhoun, Jackson, Refugio, and Victoria counties for the six methods for generating water levels surfaces. The difference among the methods varied considerably in regard to county and to the year. Two conclusions deduced from the three figures are:

- All of the method that involved Kriging had similar patterns in the direction of the fluctuations but the magnitude of those fluctuations greatly varied.
- The average annual water levels determined for (GAM_SSWL) (Method #5) and the GAM simulated water levels (GAM_SWL) were consistently very similar for all counties and aquifers – their lines usually differed by less than 1 foot and they exhibited considerably less fluctuations than the other methods.

Table D-2 was assembled to assess the sensitivity of the annual changes in the average water levels against the annual changes for the SSWL+KR (Method #1), which are provided in Tables 5-1 to 5-4. The average differences in Table D-2 were determined by averaging the absolute value of the difference the annual change between a method and Method #1. Among some of the notable observations from Table D-2 are:

- The Kriged values results are not very sensitive to the amount the GAM simulated water level are smoothed to generate the trend surface used for detrending.
- The Kriged results can be very sensitive if the trend surface trend surface is updated to account for annual differences in the GAM simulations that account for different pumping rates.
- The Kriging of water levels without detrending can produce significantly different results than Kriging with detrending.
- The results for the Evangeline Aquifer are more sensitive to changes how Kriging is performed than results for the Chicot Aquifer.

Table D-2 Average difference between Methods #2 through #6 with Method #1 (SSWL+KR) for the change in annual average water level from 2000 to 2020.

	#2 Simulated smoothed 2000 WLs + Kriged WL residuals	#3 Simulated WLs + Kriged WL residuals	#4 Kriged Measured WLs	#5 Simulated WLs from GAM	#6 Smoothed simulated WLs from GAM	Average of the Five Alternative Methods
County	Chicot Aquifer					
Calhoun	1.1	0.8	3.4	3.3	3.2	2.3
Jackson	1.0	1.4	2.2	5.5	5.3	3.1
Refugio	0.9	1.5	4.3	4.7	4.8	3.3
Victoria	6.7	1.2	2.9	8.4	7.9	5.4
Average	2.4	1.2	3.2	5.5	5.3	3.5
County	Evangeline Aquifer					
Calhoun	15.4	4.3	16.6	11.2	11.5	11.8
Jackson	17.3	1.4	5.0	13.6	14.0	10.2
Refugio	4.9	2.3	8.0	5.0	5.0	5.0
Victoria	12.0	3.4	3.5	4.4	4.4	5.5
Average	12.4	2.9	8.3	8.5	8.7	8.2
County	Chicot & Evangeline Aquifer					
Calhoun	3.4	1.0	2.8	2.9	2.9	2.6
Jackson	8.4	1.2	2.9	5.3	5.6	4.7
Refugio	2.4	1.7	5.0	4.2	4.2	3.5
Victoria	9.3	1.4	2.8	3.3	3.1	3.9
Average	5.9	1.3	3.4	3.9	3.9	3.7

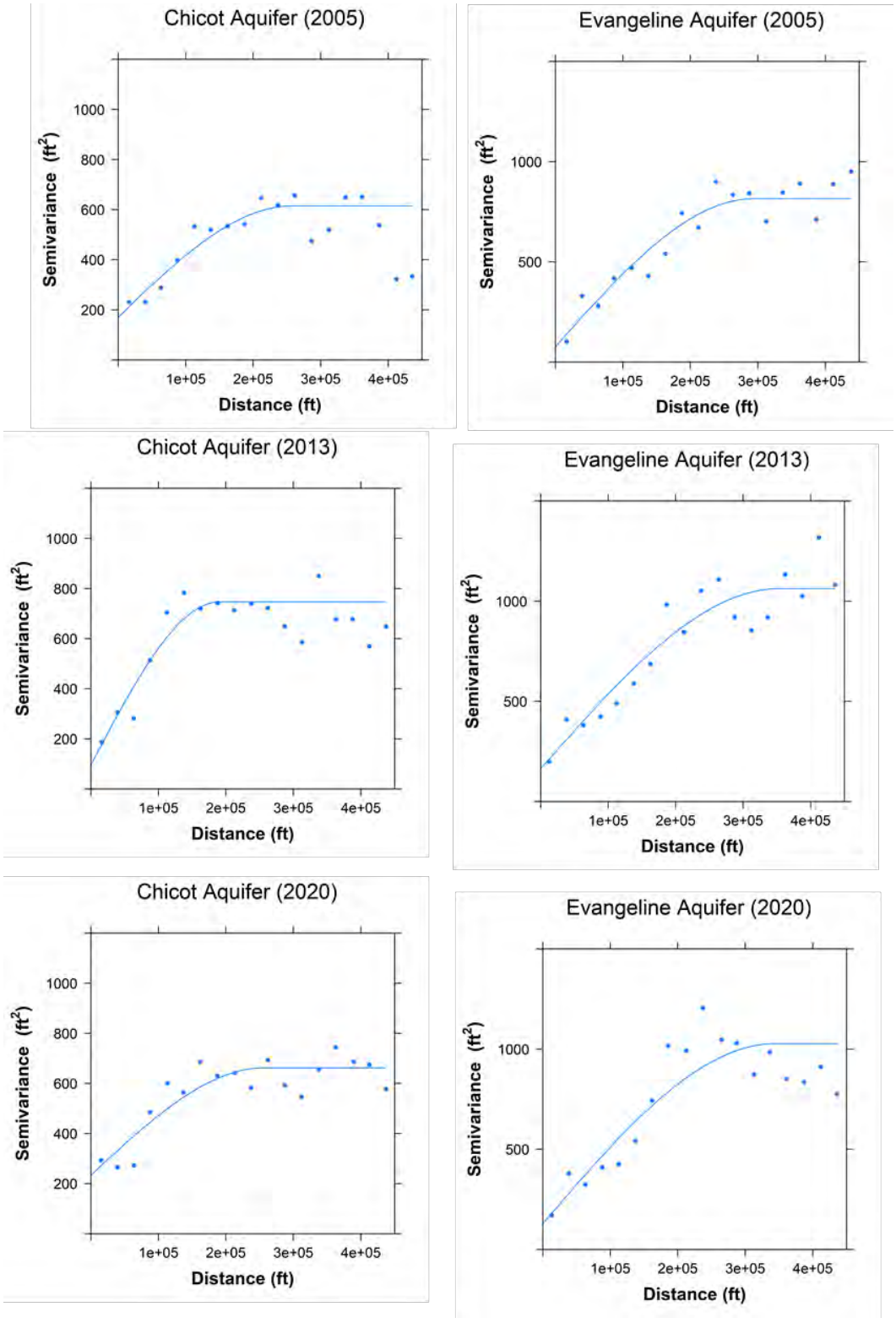

Figure D-1 Example experimental and theoretical semivariograms for the Simulated smoothed 2000 WLs + Kriged residuals (SWSL2000+KR)

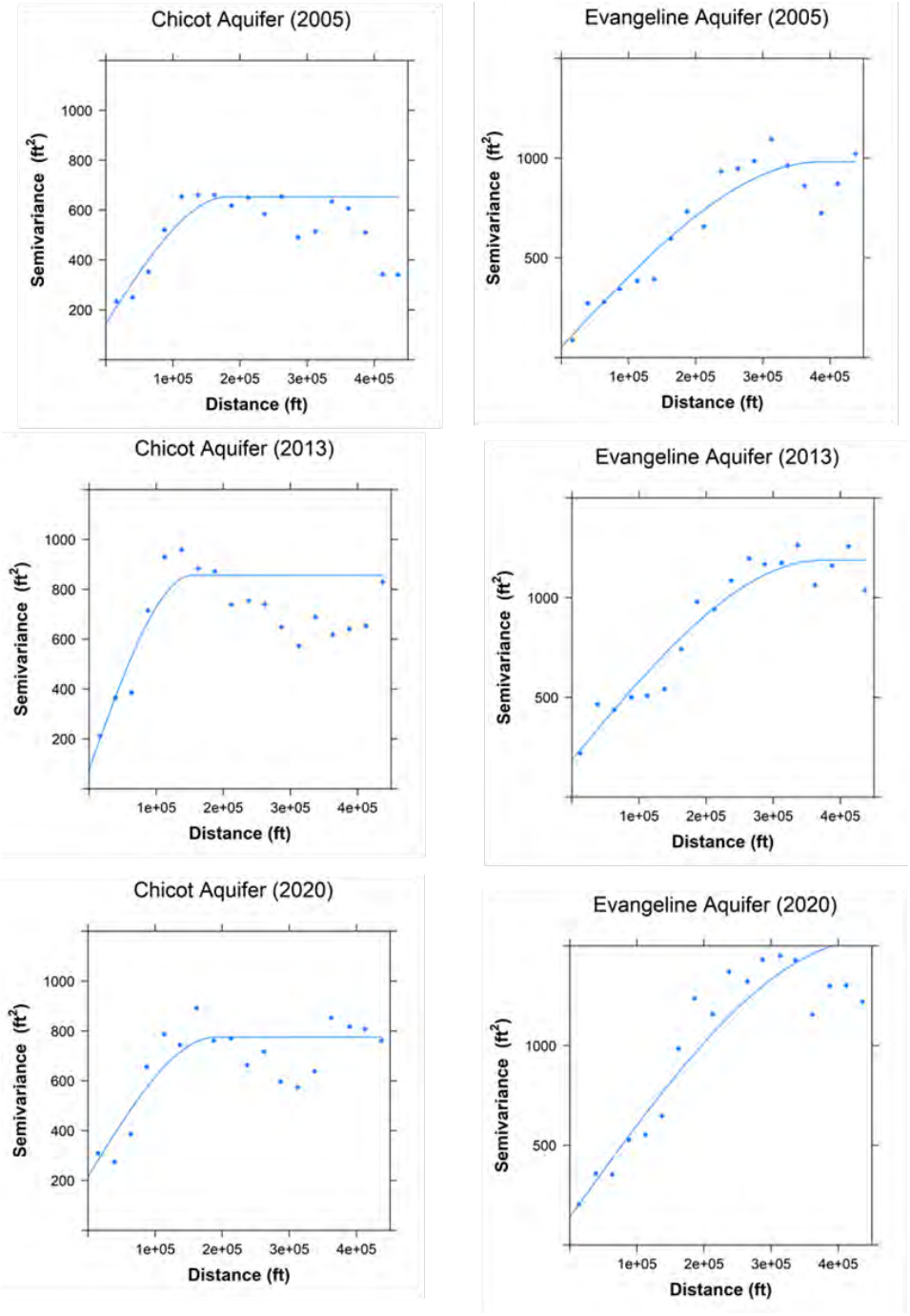

Figure D-2 Example experimental and theoretical semivariograms for the Simulated WLs + Kriged WLs residuals (SWLs+KR) method

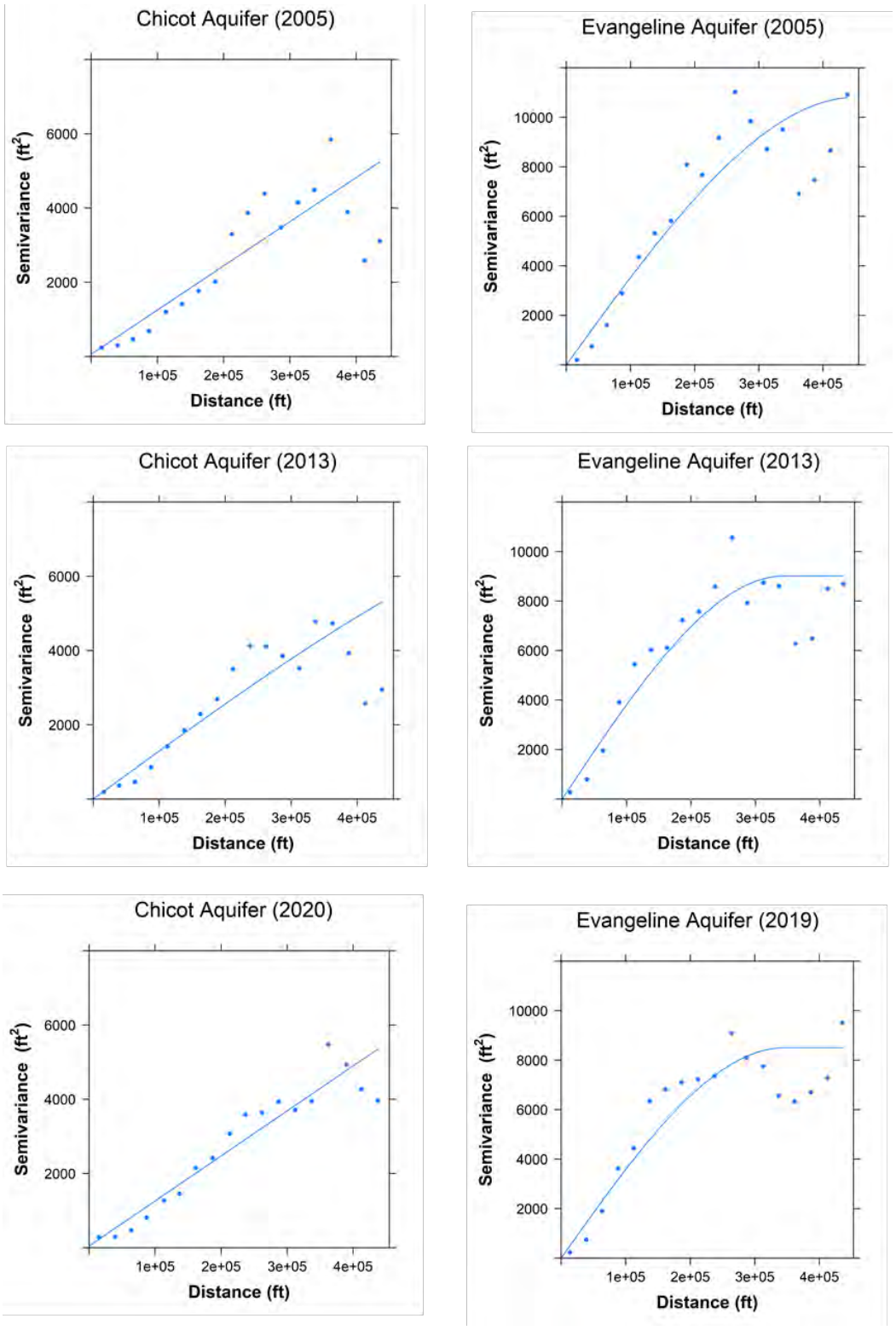

Figure D-3 Example experimental and theoretical semivariograms for the Kriged Measured WLs (KWL) method

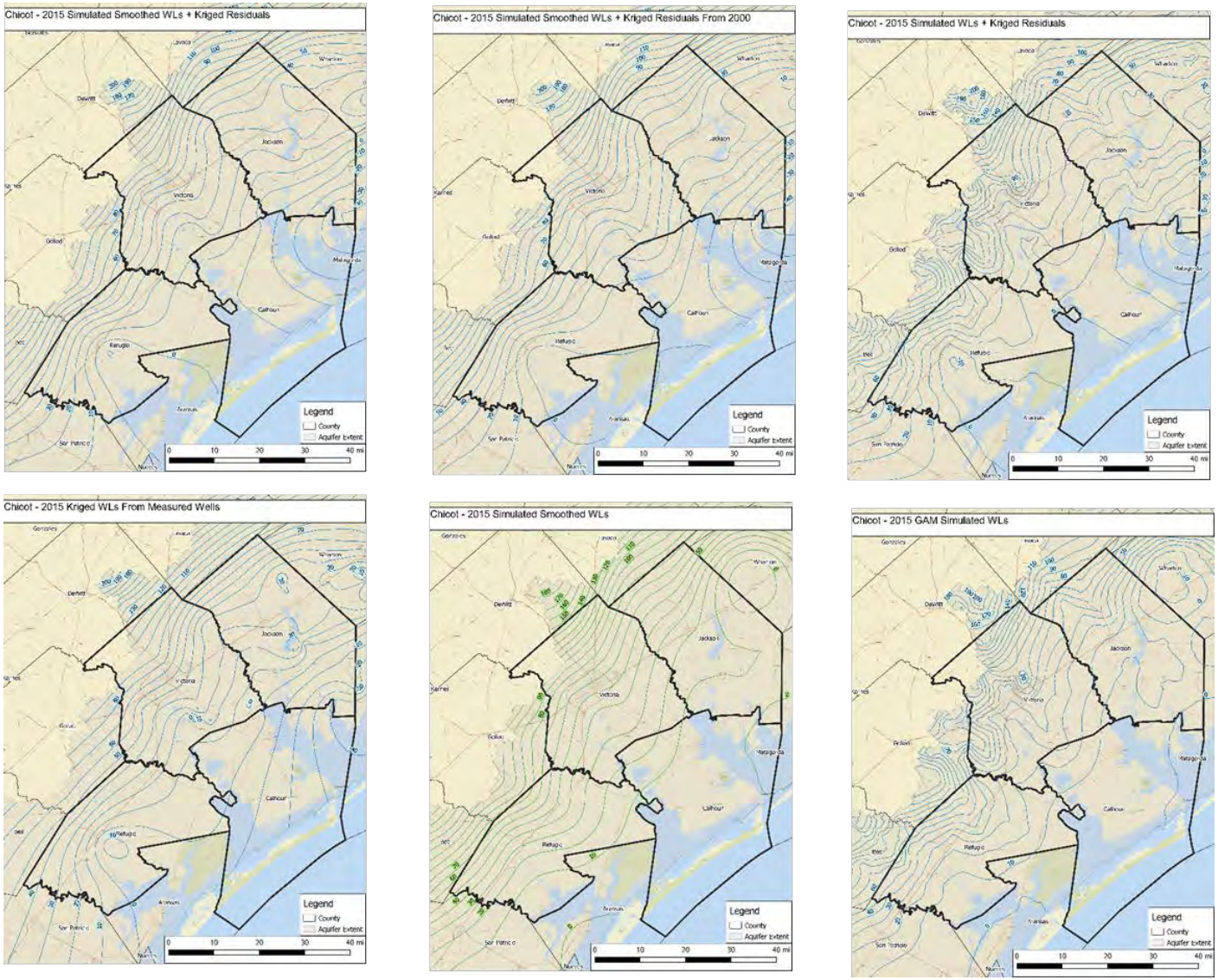

Figure D-4 Comparison of 2015 water level contours for Chicot Aquifer produced by the six methods described in Table 5-5. 1) SSWL+KR, 2) SSWO2000+KR, 3) SWLs+KR, 4) KWL, 5) GAM_SSWL, and 6) GMA_SWL

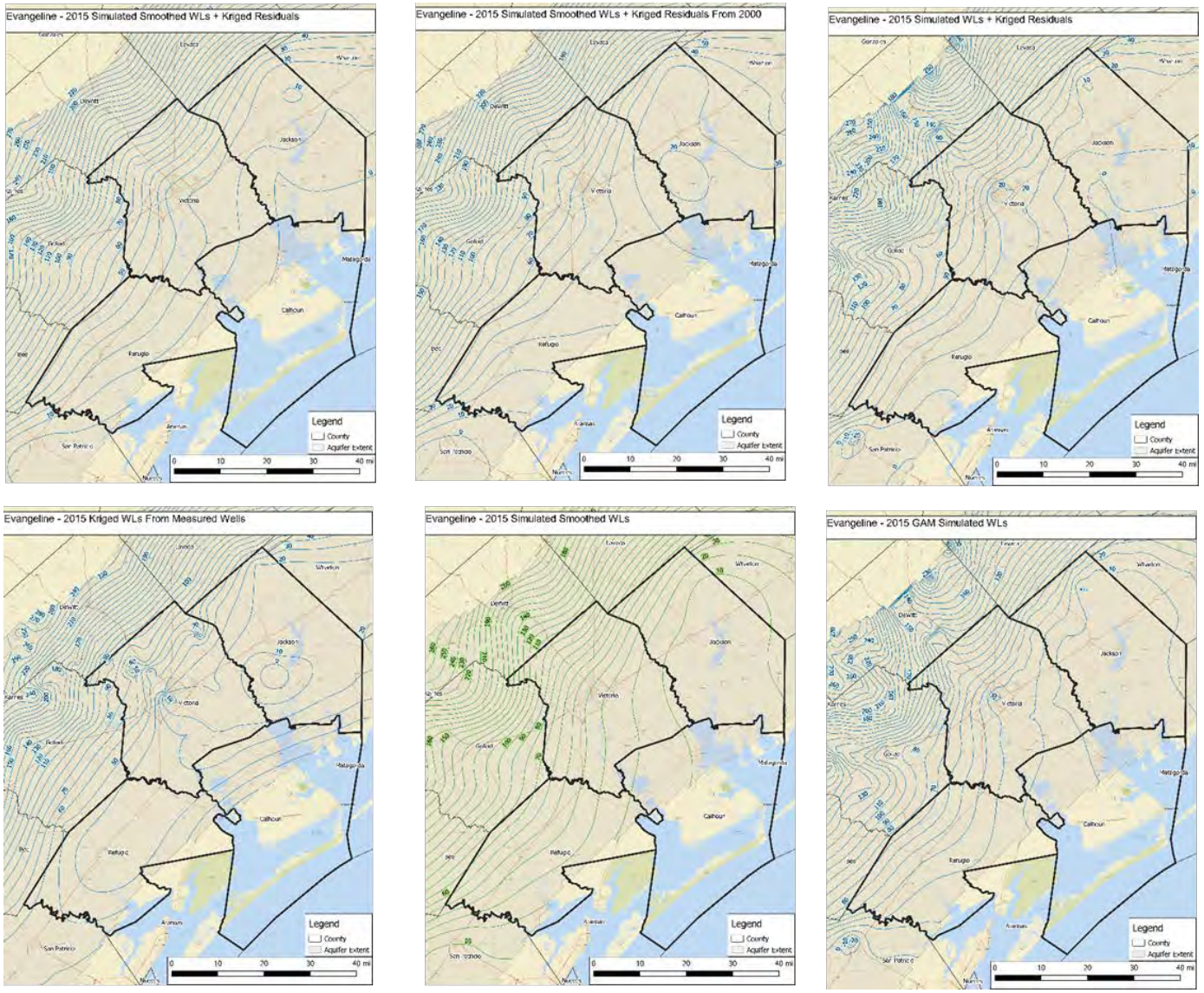

Figure D-5 Comparison of 2015 water level contours for Evangeline Aquifer produced by the six methods described in Table 5-5. 1) SSWL+KR, 2) SSWO2000+KR, 3) SWLs+KR, 4) KWL, 5) GAM_SSWL, and 6) GMA_SWL

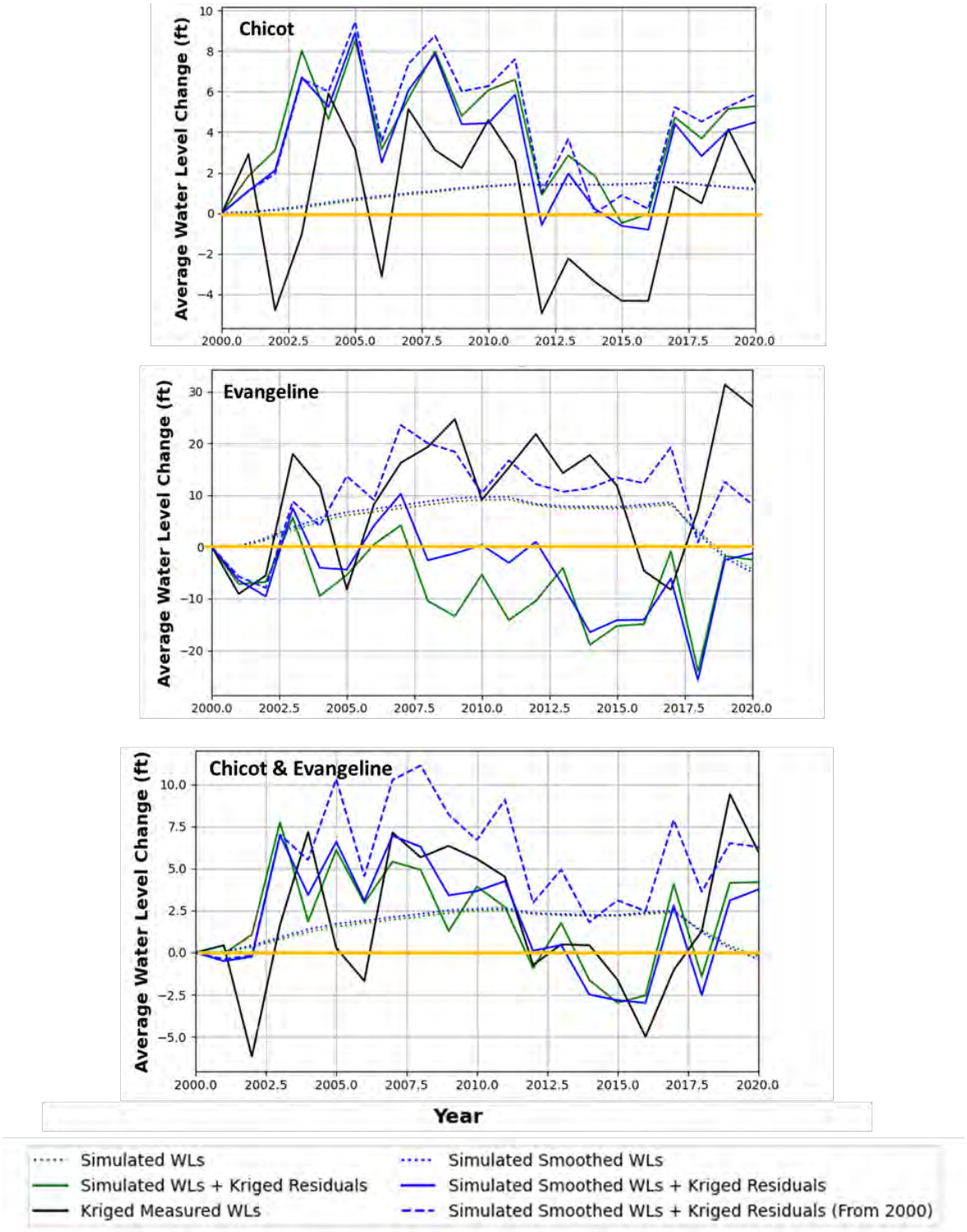

Figure D-6 Changes in the annual average water levels from five alternative methods and Simulated Smoothed WLs + Kriged residuals (SSWL+KR), which is considered to be Best Science Available for Calhoun County

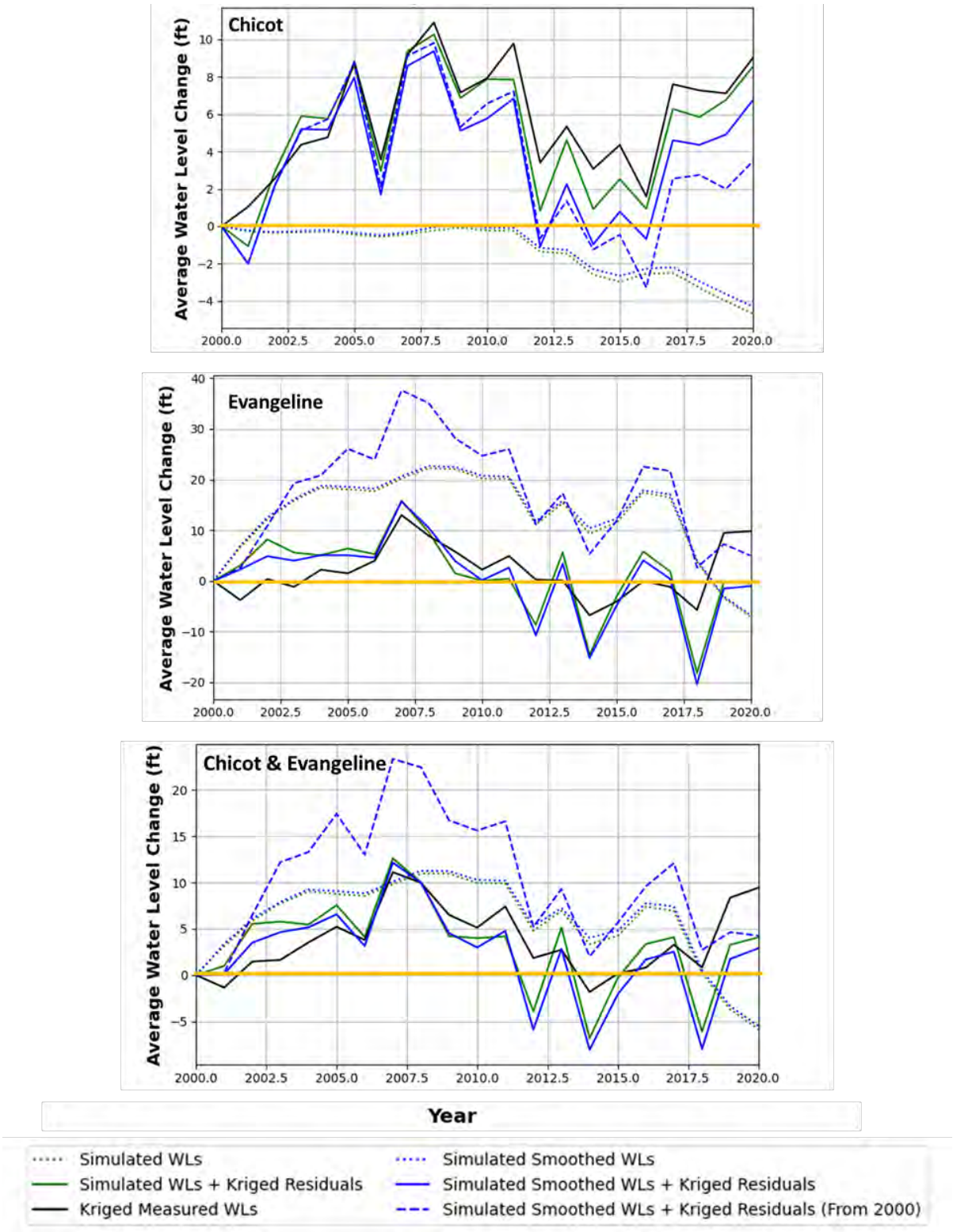

Figure D-7 Changes in the annual average water levels from five alternative methods and Simulated Smoothed WLs + Kriged residuals (SSWL+KR), which is considered to be Best Science Available for Jackson County

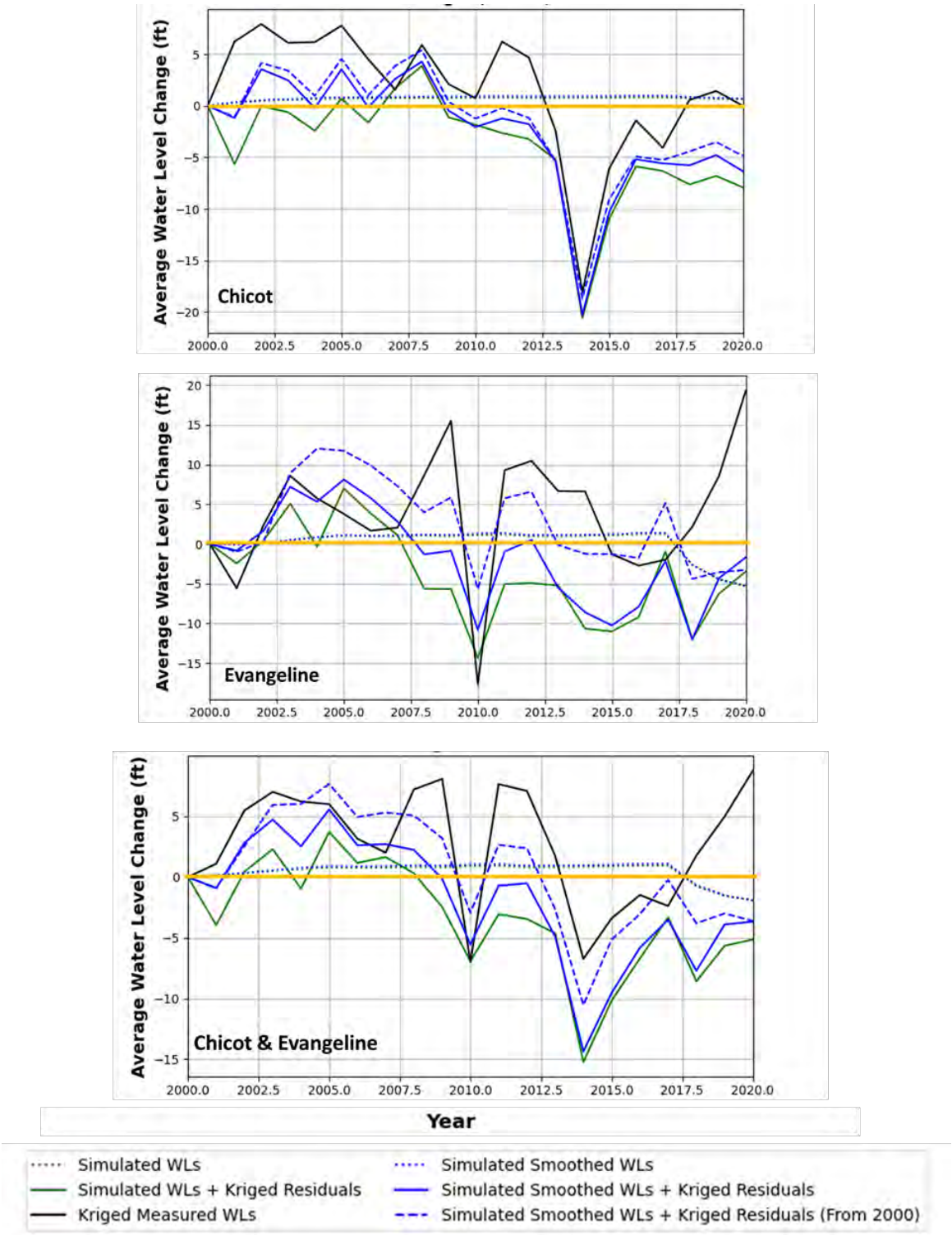

Figure D-8 Changes in the annual average water levels from five alternative methods and Simulated Smoothed WLs + Kriged residuals (SSWL+KR), which is considered to be Best Science Available for Refugio County

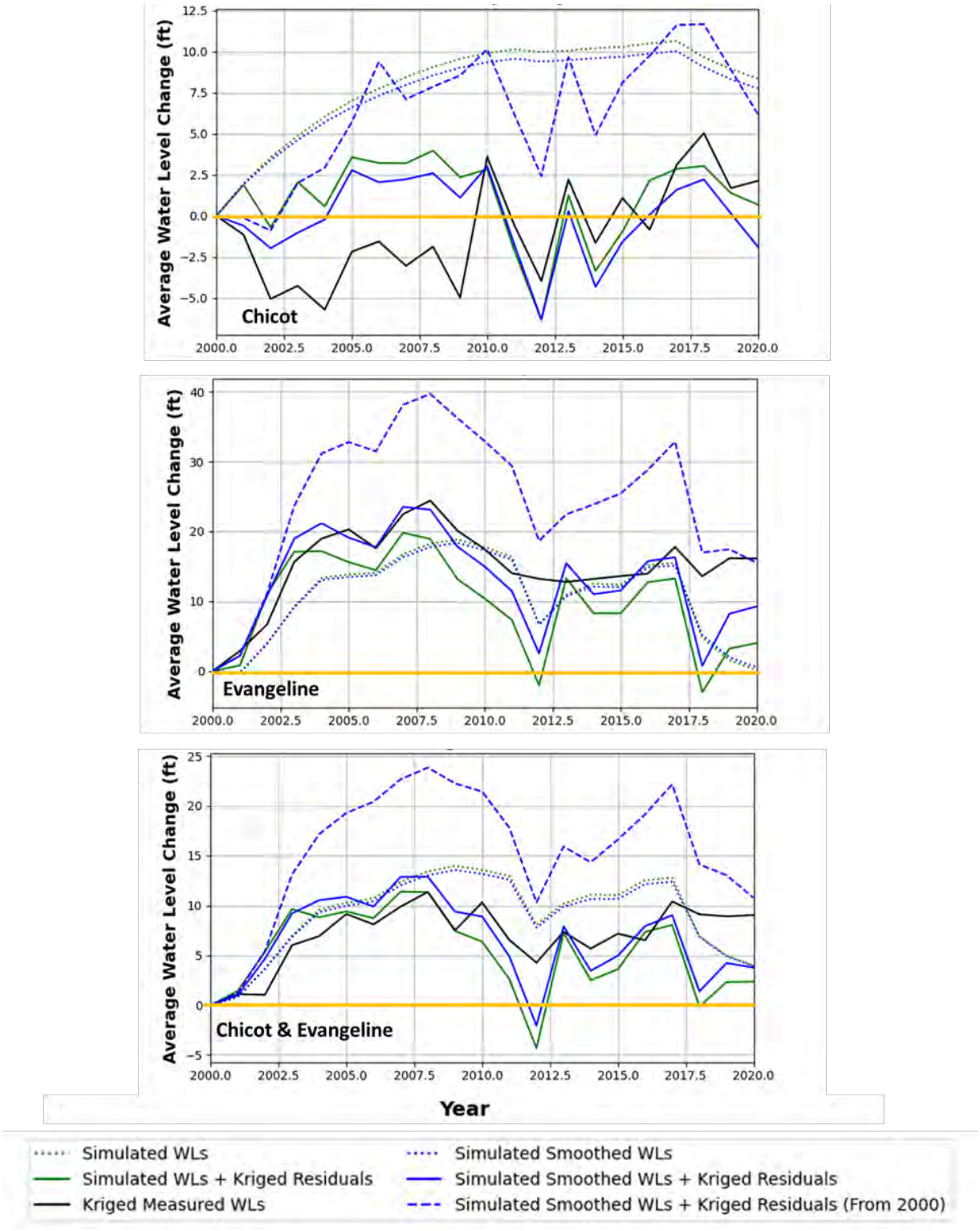

Figure D-9 Changes in the annual average water levels from five alternative methods and Simulated Smoothed WLs + Kriged residuals (SSWL+KR), which is considered to be Best Science Available for Victoria County