APPENDIX G4. SEA LEVEL RISE ANALYSIS

Sea Level Rise Analysis

Introduction

Current project status calls for analysis of the impact sea level rise (SLR) might have on the final design crest height of the levee at Huntington, VA. To determine this impact, existing HEC-RAS models were re-run to measure the impact that raising the downstream section water level might have on the upstream area where the levee sits. Impacts were measured for the 1% annual chance flood, which is the project design flood, for both sea level rise over a 50-yr period and a 90-yr period. A 50-year period was chosen because that is typically the duration that is used when determining the economic costs and benefits of a Corps flood damage reduction project. The project team also wanted to look at the impact over a longer period of time and since the National Research Council (NRC) report only makes SLR predictions to the year 2100, we selected a 90-year period (assumes the year 2010 to year 2100). Current USACE standards call for consideration of local historic rates, projected NRC rates, and projected Intergovernmental Panel on Climate Change (IPCC) rates when planning and designing projects that could be affected by sea level rise. Estimates for both the 50-yr and 90-yr SLR rates were made from each of these reports and then run in HEC-RAS to determine their impact on future water levels at the levee. Plots (Figures 3-8) of the calculated water levels are included for reference.

Sea Level Rise Estimation

To estimate future sea level rise at Huntington, various sources were studied to arrive at three separate estimates. Any long term localized SLR estimate should take into account both eustatic SLR, which is the change in global average sea level from an increase in the world ocean volume, and relative land subsidence/uplift. The resulting rate is the *relative SLR rate*, the sum of the two aforementioned parameters. The three estimates used are a local historical estimate based on local tide gauge data, an empirical estimate from the 1987 NRC report based on time-dependent curves accounting for future accelerations in relative sea level rise rates, and an estimate from the 2007 IPCC report based on recent data from 1980-1999 projected to the decade 2090-2099. The local historical estimate includes the effects of local subsidence but the NRC and IPCC reports only consider eustatic rises.

The best sources of information for historic sea level trends are local tide gauges. For this study, data from the nearest NOAA tide gauge, Station ID 8594900, in Washington D.C. were used to estimate SLR for Huntington. According to this gauge, mean sea level has risen roughly 0.933 ft per 90-yrs based on monthly mean sea level data from 1924 to 2006. Likewise, the 50-yr local historic SLR estimate is 0.52 ft per half century.

Since the tide gauge at Station ID 8594900 is fixed relative to the land, it is measuring the vertical motion of the land as well as changes in the level of the ocean. If the land is rising at the same rate as the ocean, the long-term sea-level record at the

station will show a trend of zero. Only if the land is stationary will the gauge record the absolute (eustatic) rate of the rise of the ocean. If the land is sinking, the relative sea-level trend recorded at that location will be greater than the eustatic global sea-level rise. Long-term changes to a coastline at a particular location will depend on the relative sea-level rate, which includes the local vertical land motion as well as the absolute eustatic rate of rise of the global ocean.

The 1987 NRC report and its estimates are based on the assumption that there is a high probability that global SLR will greatly accelerate with time and that there are uncertainties associated with these estimations. Potential relative sea level change should be considered in every coastal and estuarine feasibility study that the USACE undertakes (as far inland as estimated tidal influence extends). Fluvial studies (such as flood studies) that include backwater profiling shall also consider the effects of potential relative sea-level change by including potential relative sea-level change in the starting water surface elevation for such profiles, where appropriate. The degree of consideration that the possible change receives will depend upon the historical record for the study site.

To account for the uncertainties of future SLR accelerations, the NRC report examines three eustatic rises to the year 2100 from 1987: 1.64 ft (0.5 m), 3.28 ft (1 m), and 4.92 ft (1.5 m). Three possible scenarios were created, each with a different SLR acceleration rate and corresponding curve. These three curves are shown in Figure 1.

As shown in Figure 1, Curve 1 corresponds to a 0.46 m (1.51 ft) rise per 90-yrs and 0.14 m per half century, Curve 2 a 0.94 m (3.08 ft) rise per 90-yrs and 0.29 m per half century, and Curve 3 a 1.42 m (4.66 ft) rise per 90-yrs and 0.42 m per half century. For the HEC-RAS modeling, rates for Curves 1 and 3 were used to provide results for the minimum and maximum estimations.

The IPCC report examines six climate evolution scenarios. However, only the rise and rate of rise for two scenarios (B1 and A1F1) are contained in Table 1 below. Scenarios B1 and A1F1 give the extreme values (smallest and greatest, respectively) of the six scenarios; the remaining four scenarios give values intermediate between B1 and A1F1. Note that the *rates of rise* shown in Table 1 assume a linear trend between the 19 year period 1980 to 1999 and the nine year period 2090 to 2099. Figure 2 presents the NRC curves from Figure 1 in addition to the 95% confidence limits of the B1 and A1F1 scenarios shown in Table 1.

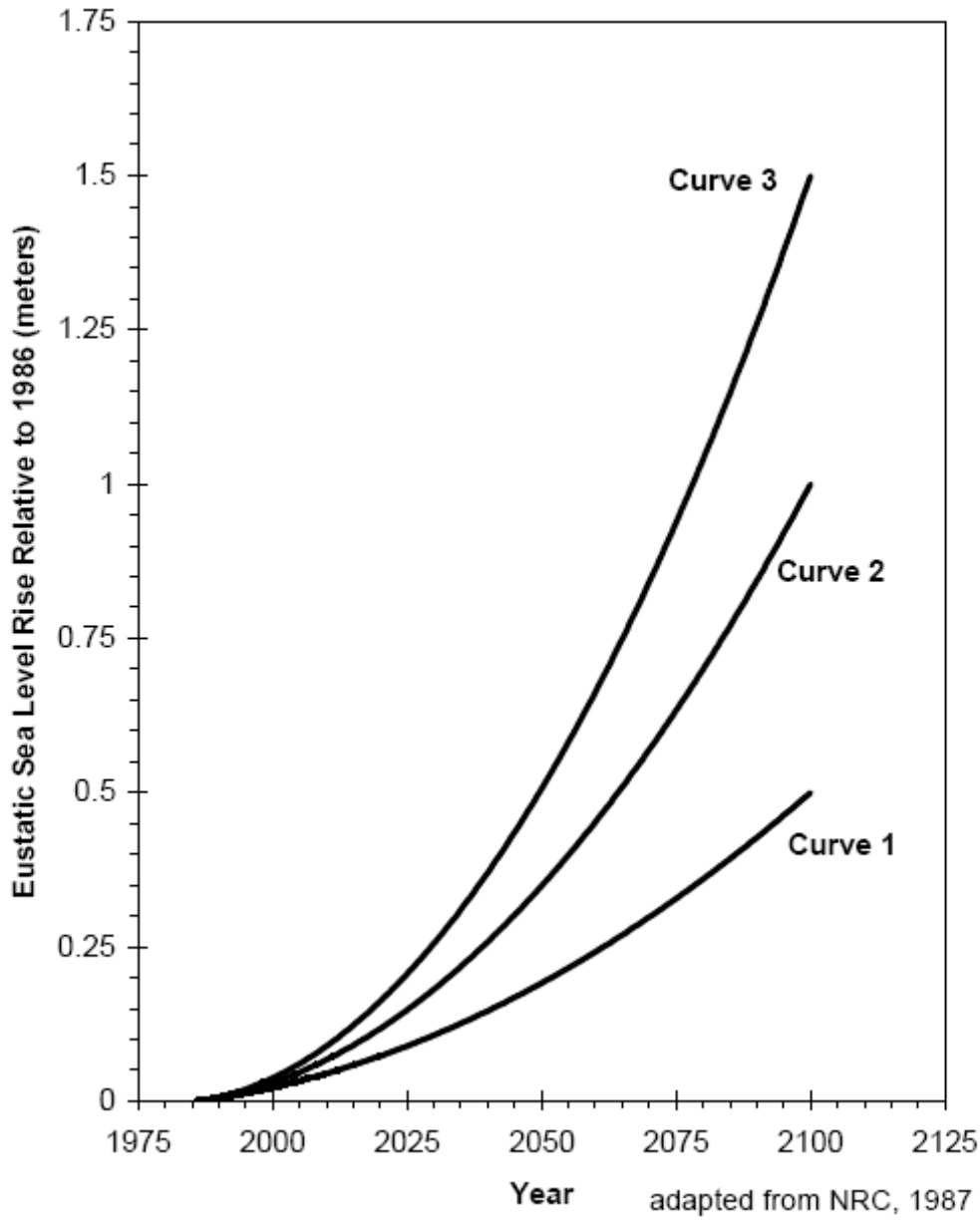

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Figure 1. Scenarios for Global Eustatic Sea Level Rise (after NRC 1987, Figure 2.2).

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	B1		A1F1	
	5% CL	95% CL	5% CL	95% CL
Sea Level Rise (m)	0.18 (0.59 ft)	0.38 (1.25 ft)	0.26 (0.85 ft)	0.59 (1.94 ft)
Rate of Sea Level Rise (mm/yr)	1.5 (0.0049 ft)	3.9 (0.013 ft)	3.0 (0.0098 ft)	9.7 (0.032 ft)

Table 1. Projected global average sea level rise components during the 21st century. The upper row in each pair gives the 5% and 95% confidence limit (m) of the rise in sea level between 1980 to 1999 and 2090 to 2099. The lower row in each pair gives the range of the rate of sea level rise (mm yr^{-1}) during 2090 to 2099 (excerpted from IPCC 2007a, Table 10.7).

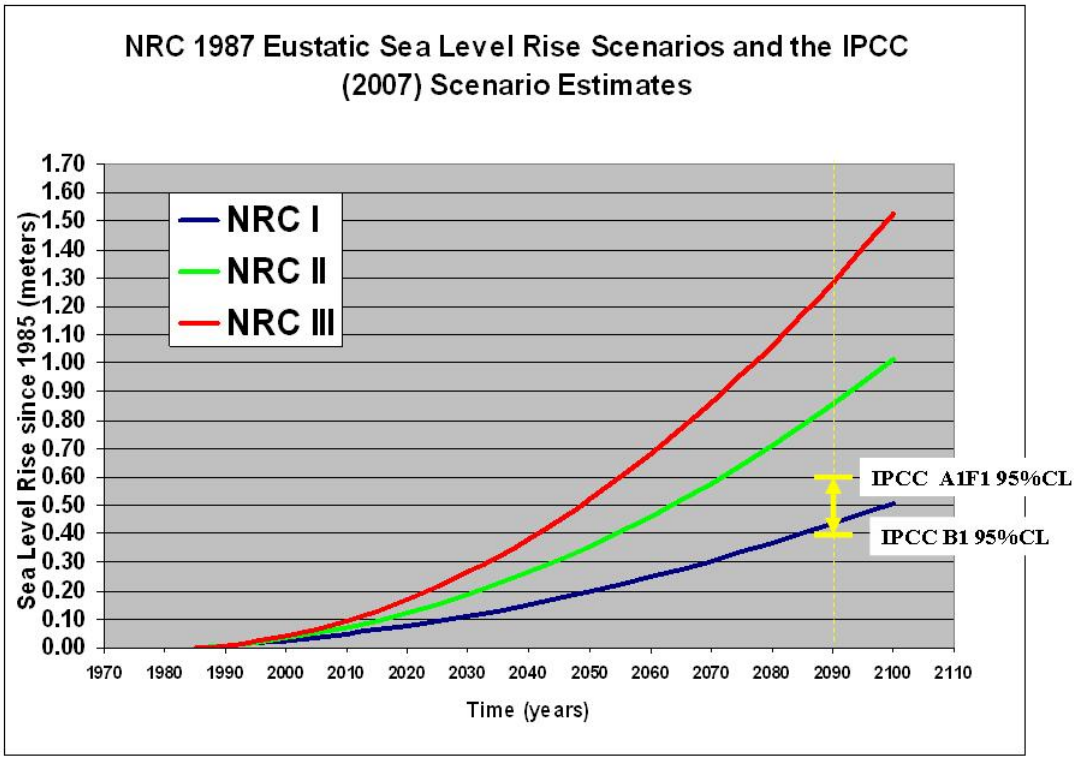

Figure 2. NRC (1987) eustatic sea level rise scenarios and the IPCC (2007) scenario estimates for use in predicting future sea level change.

Based on the IPCC rates in Table 1, A1F1 provides sea level rises of 1.94 ft per 90-yrs and 1.08 ft per half century. Likewise, B1 provides 1.25 ft per 90-yrs and 0.69 ft per half century.

HEC-RAS Modeling

The impact of SLR was incorporated into the HEC-RAS models by simply adding the SLR values to the downstream known water surface elevation at the mouth of Cameron Run and the confluence with the Potomac River. The steady flow model was then run for the 1% annual chance flood event and the resulting water level compared to the previously accepted plan in which the downstream end of the levee is at elevation 16.8 ft (2.5 ft above the 1% annual chance elevation) and the upstream end is at elevation 18.9 ft (3.5 ft above the 1% annual chance elevation).

The SLR values used were the minimums and maximums from the NRC report and the IPCC report for both the 50-yr and 90-yr periods. Since the local historic estimates are less than both the NRC and IPCC estimates, they were not included in the HEC-RAS modeling. Table 2 below shows the resulting change in water surface elevation (WSE) at both the upstream and downstream ends of the levee for each SLR value. This change is measured with respect to the WSE for the current plan as described above. Note that only the SLR of 4.66 ft by year 2100 from Curve 3 in the NRC report causes any increase in the predicted WSE at the levee. This increase is 0.3 ft at the upstream end of the levee and 0.35 ft at the downstream end.

Method		Sea Level Rise (ft)		WSE Change at Levee (ft)	
		50-yr	90-yr	50-yr	90-yr
NRC	Curve 1	0.46	1.51	0	0
	Curve 3	1.38	4.66	0	0.35 D/S, 0.3 U/S
IPCC	A1F1	1.08	1.94	0	0
	B1	0.69	1.25	0	0

Table 2. NRC and IPCC SLR rates used for HEC-RAS modeling and their corresponding impact on 1 % annual chance flood WSE upstream near the levee along Cameron Run.

Figures 3 through 10 show the WSE plots for each SLR scenarios modeled. Again, only the 4.66 ft value by the year 2100 causes any increase in WSE at the levee, or anywhere upstream of the bridge that sits roughly 400 feet upstream of the downstream control point (mouth of Cameron Run). The bridge likely dissipates the tidal influence of SLR enough that the water surface upstream does not increase for a SLR value of something less than 4.66 ft. As a check, various SLR values less than 4.66 ft were run to determine the minimum SLR at which the water level at the levee is impacted. This SLR value was found to be roughly 3.50 ft, which causes a very minimal but noticeable increase in water level at the levee (0.05’ at D/S end and less than 0.05’ at U/S end). This scenario is shown in Figure 11.

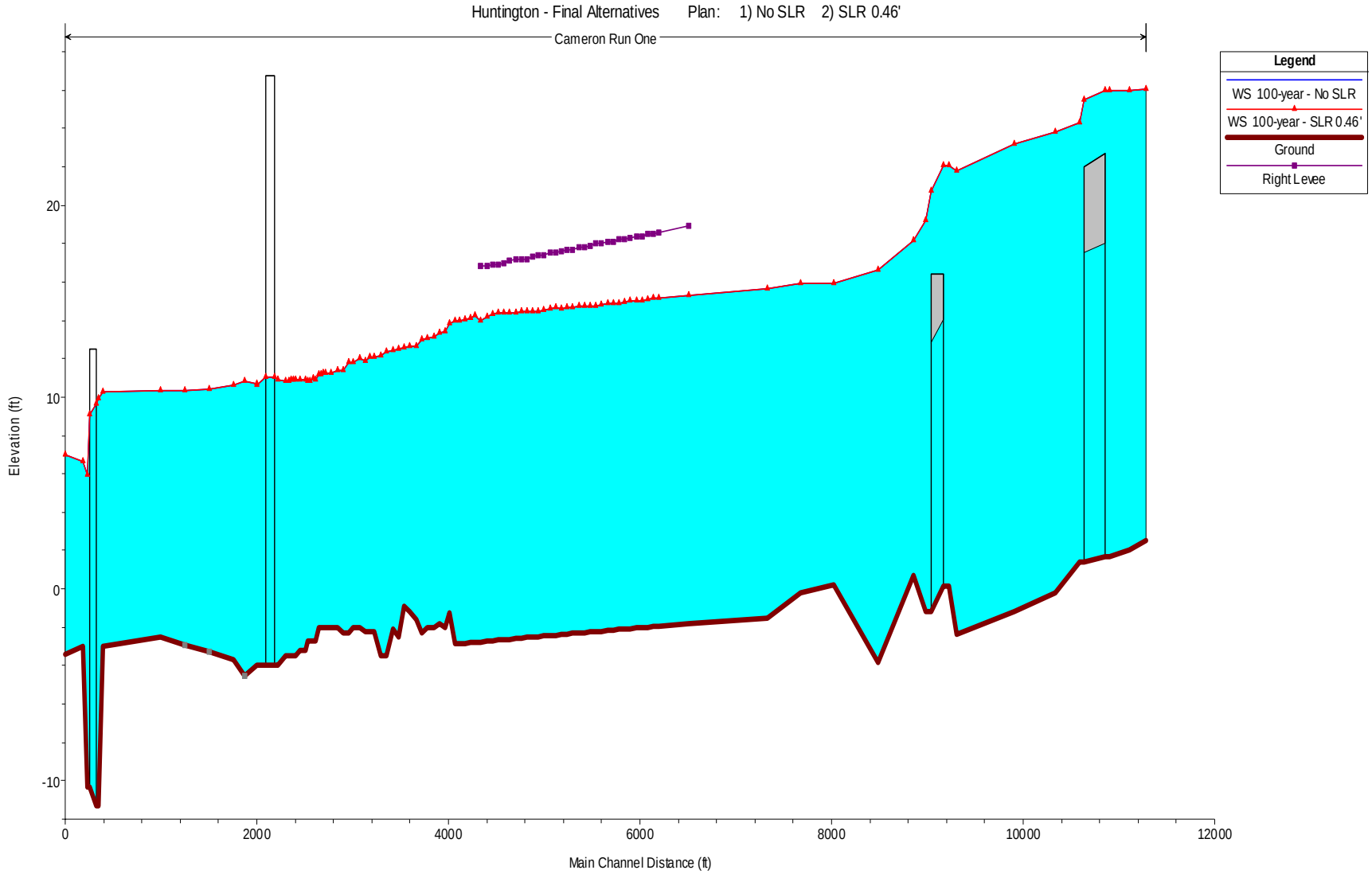

Figure 3. 1% annual chance flood water surface elevation profiles with and without SLR of 0.46 ft in 50 years.

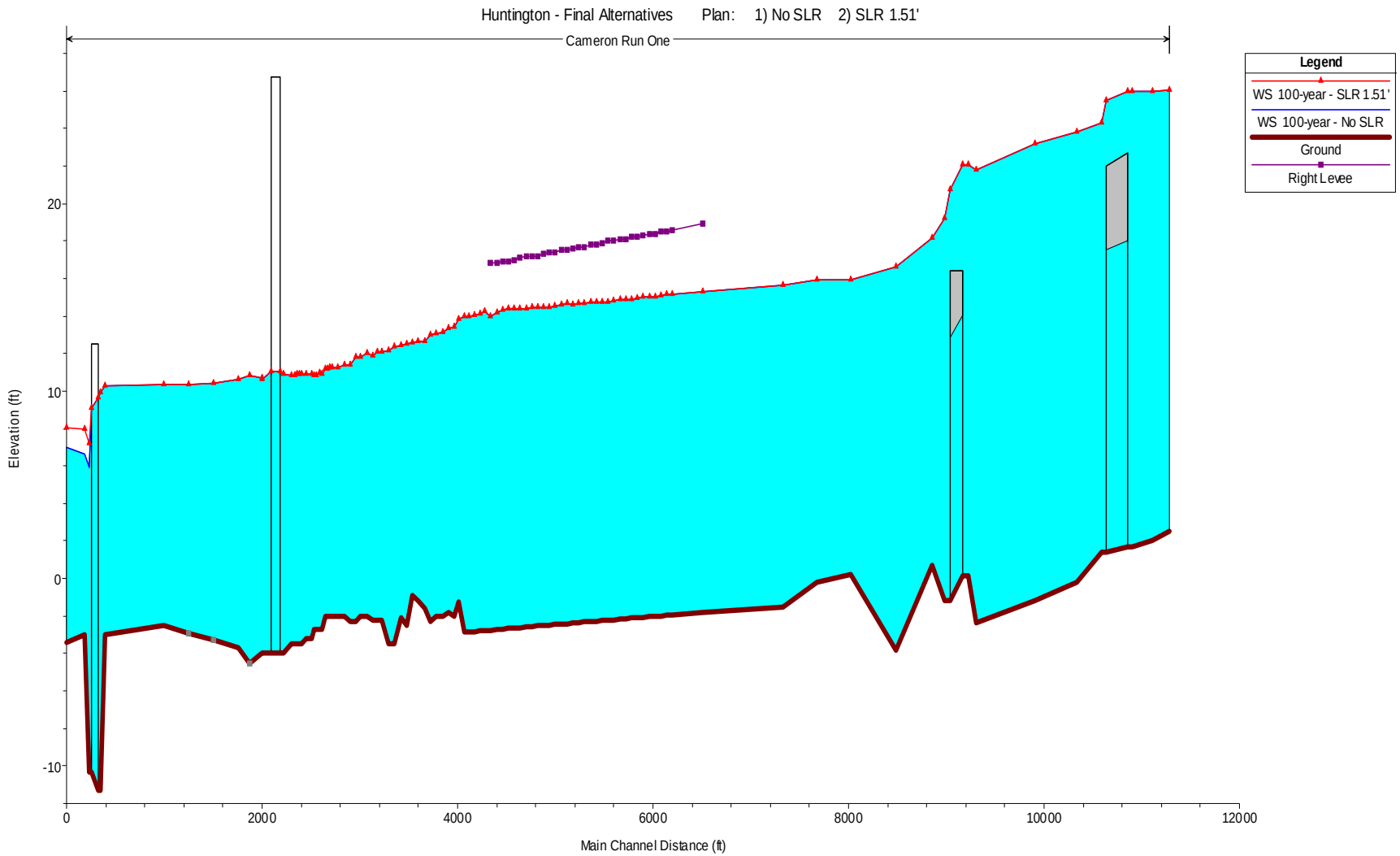

Figure 4. 1% annual chance flood water surface elevation profiles with and without SLR of 1.51 ft in 90 years.

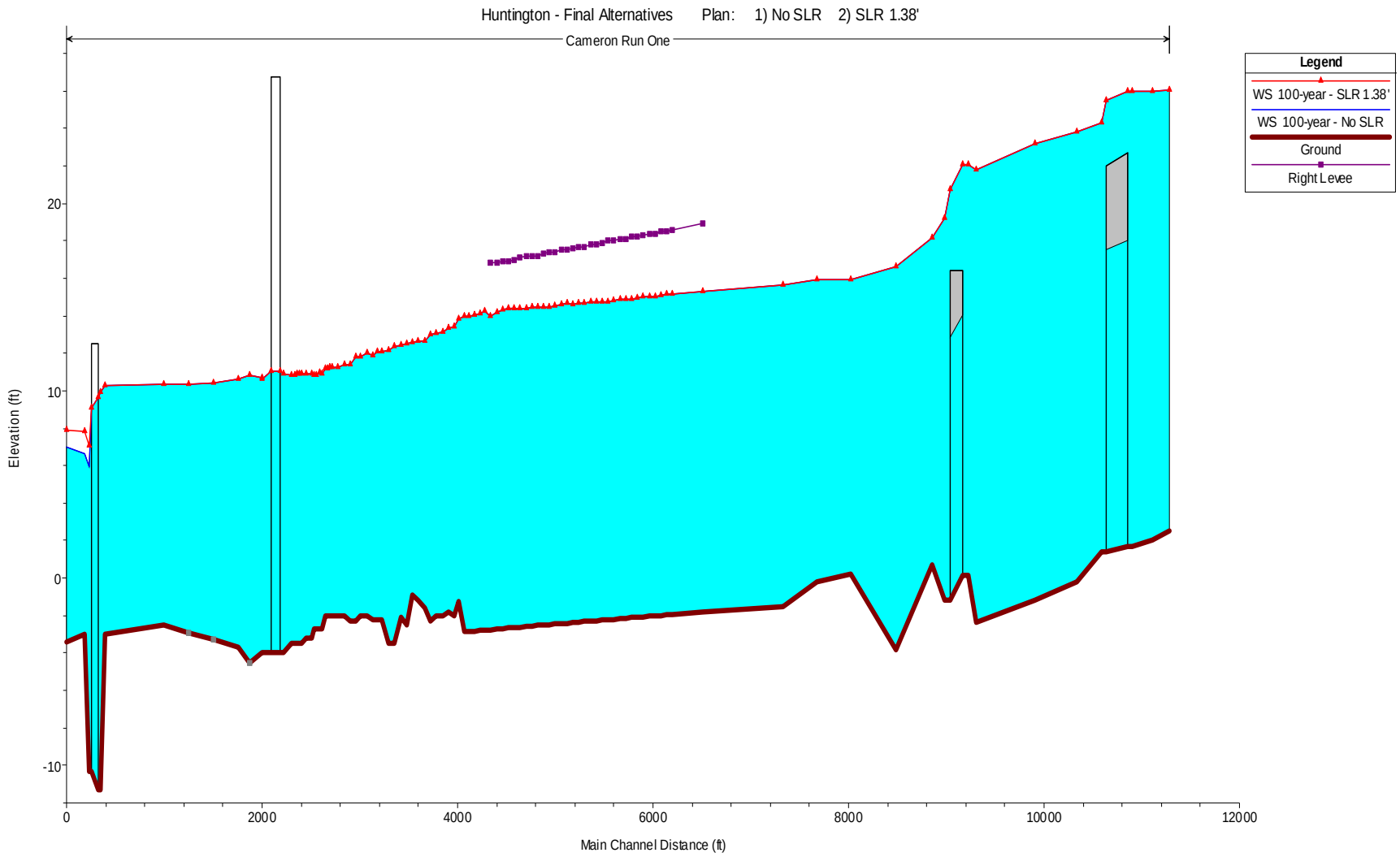

Figure 5. 1% annual chance flood water surface elevation profiles with and without SLR of 1.38 ft in 50 years.

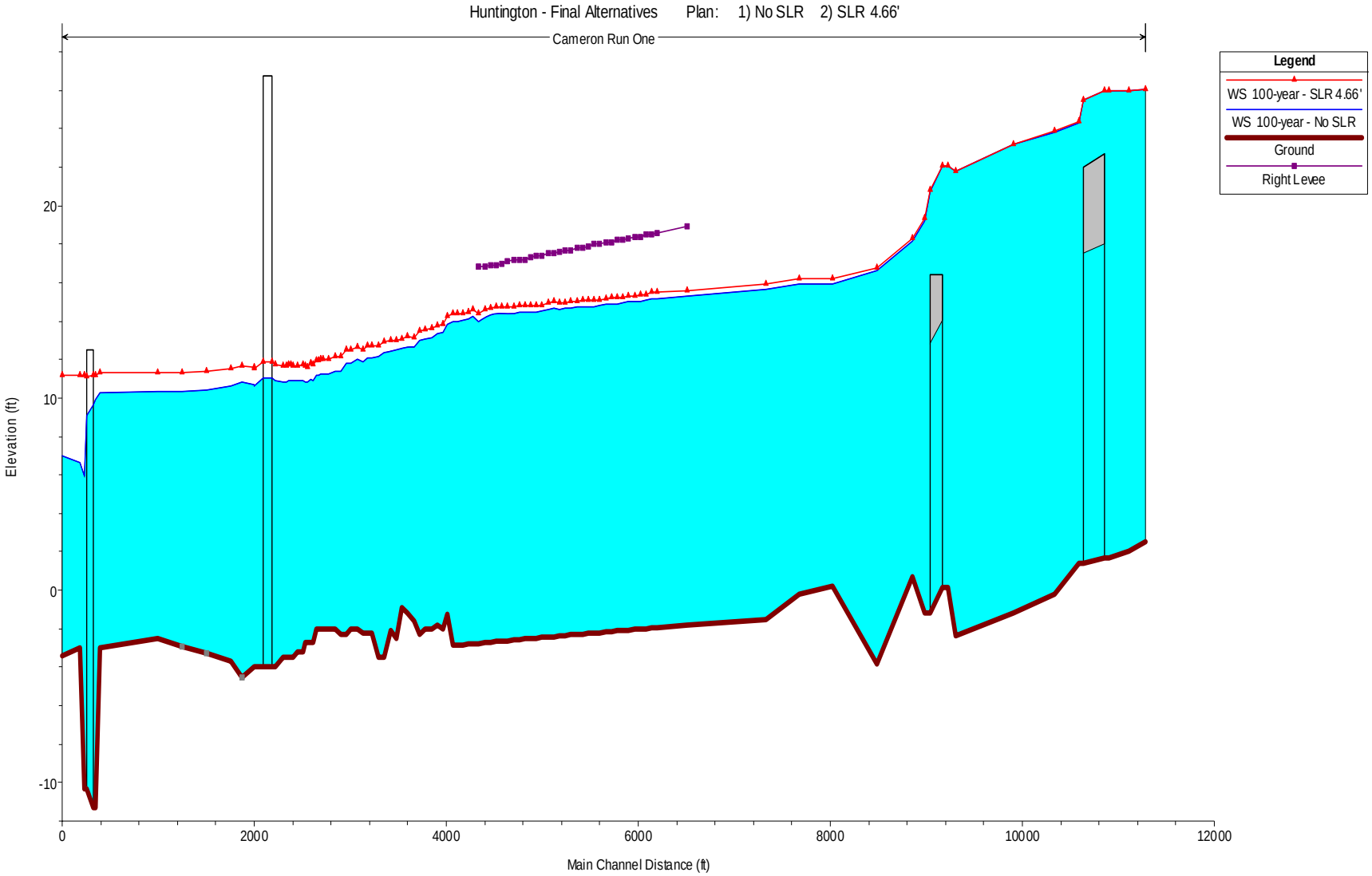

Figure 6. 1% annual chance flood water surface elevation profiles with and without SLR of 4.66 ft in 90 years.

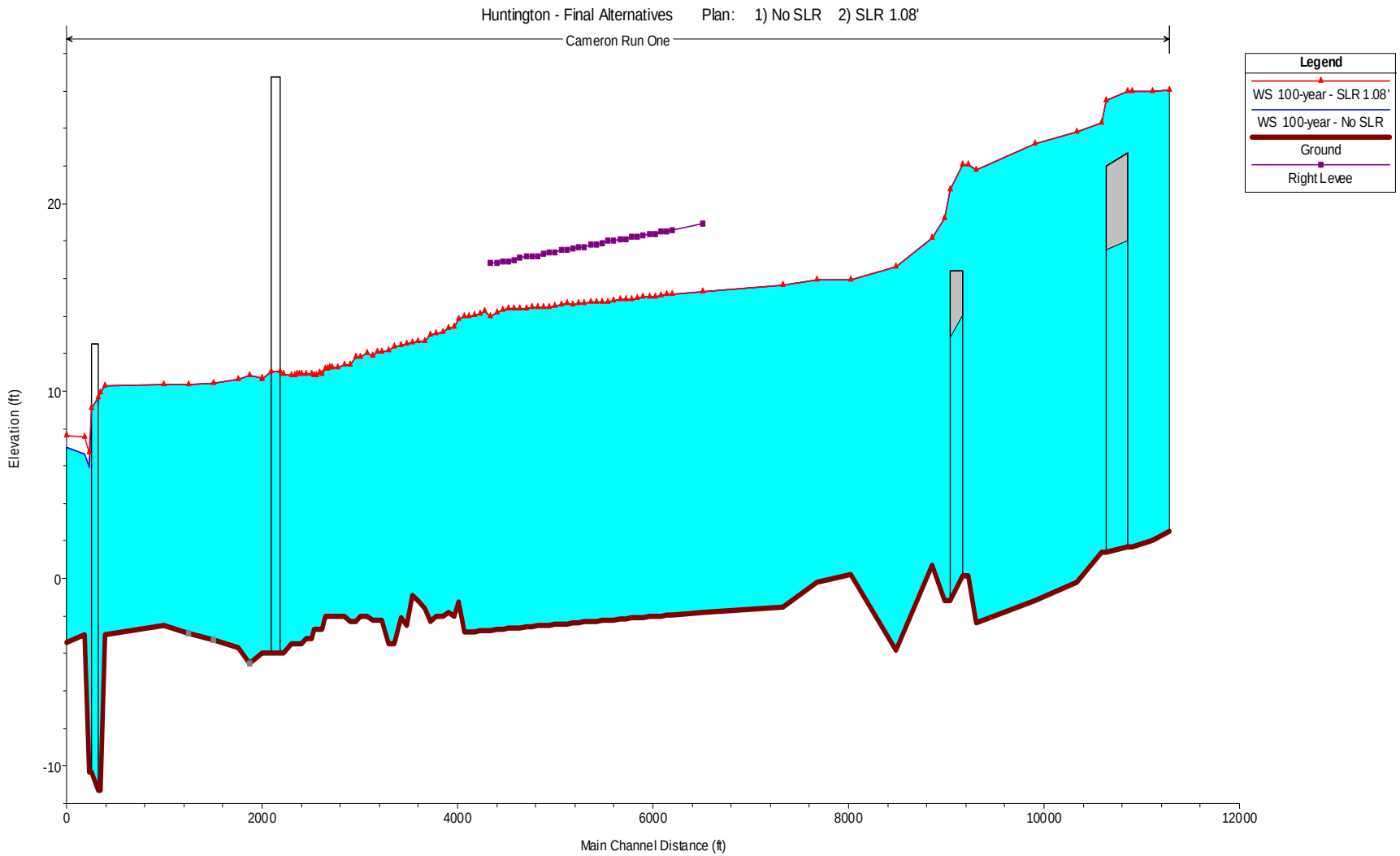

Figure 7. 1% annual chance flood water surface elevation profiles with and without SLR of 1.08 ft in 50 years.

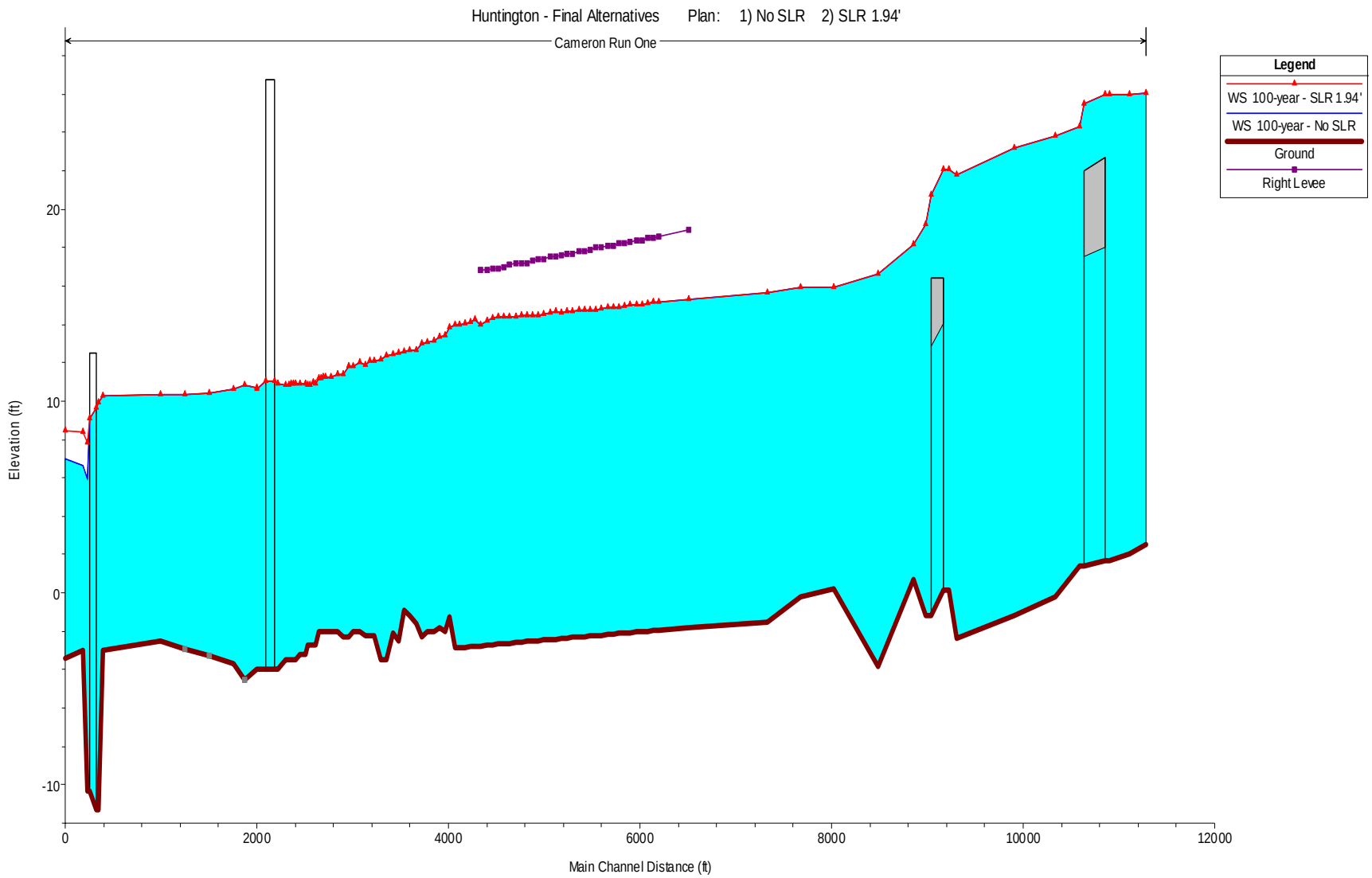

Figure 8. 1% annual chance flood water surface elevation profiles with and without SLR of 1.94 ft in 90 years.

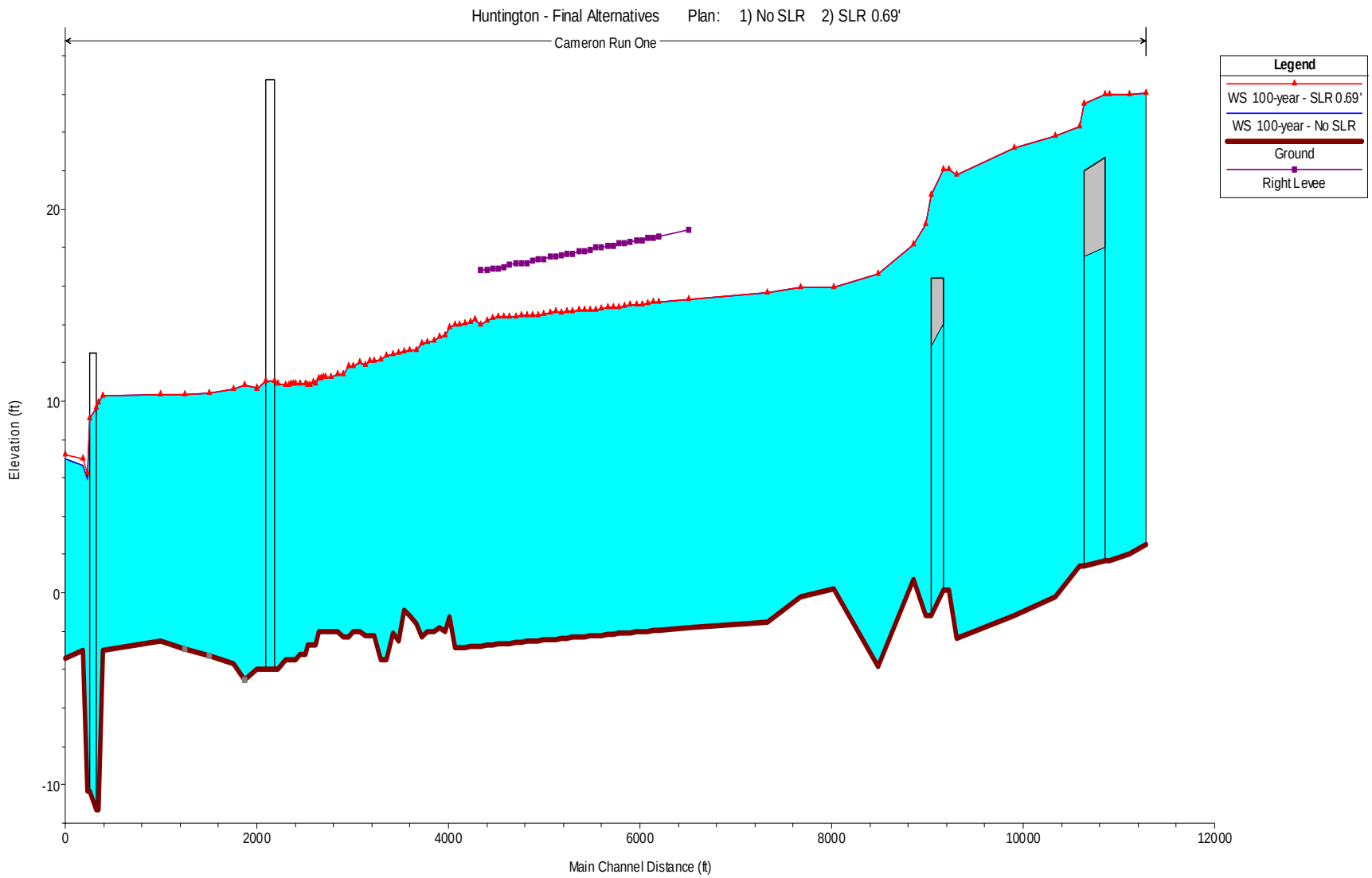

Figure 9. 1% annual chance flood water surface elevation profiles with and without SLR of 0.69 ft in 50 years.

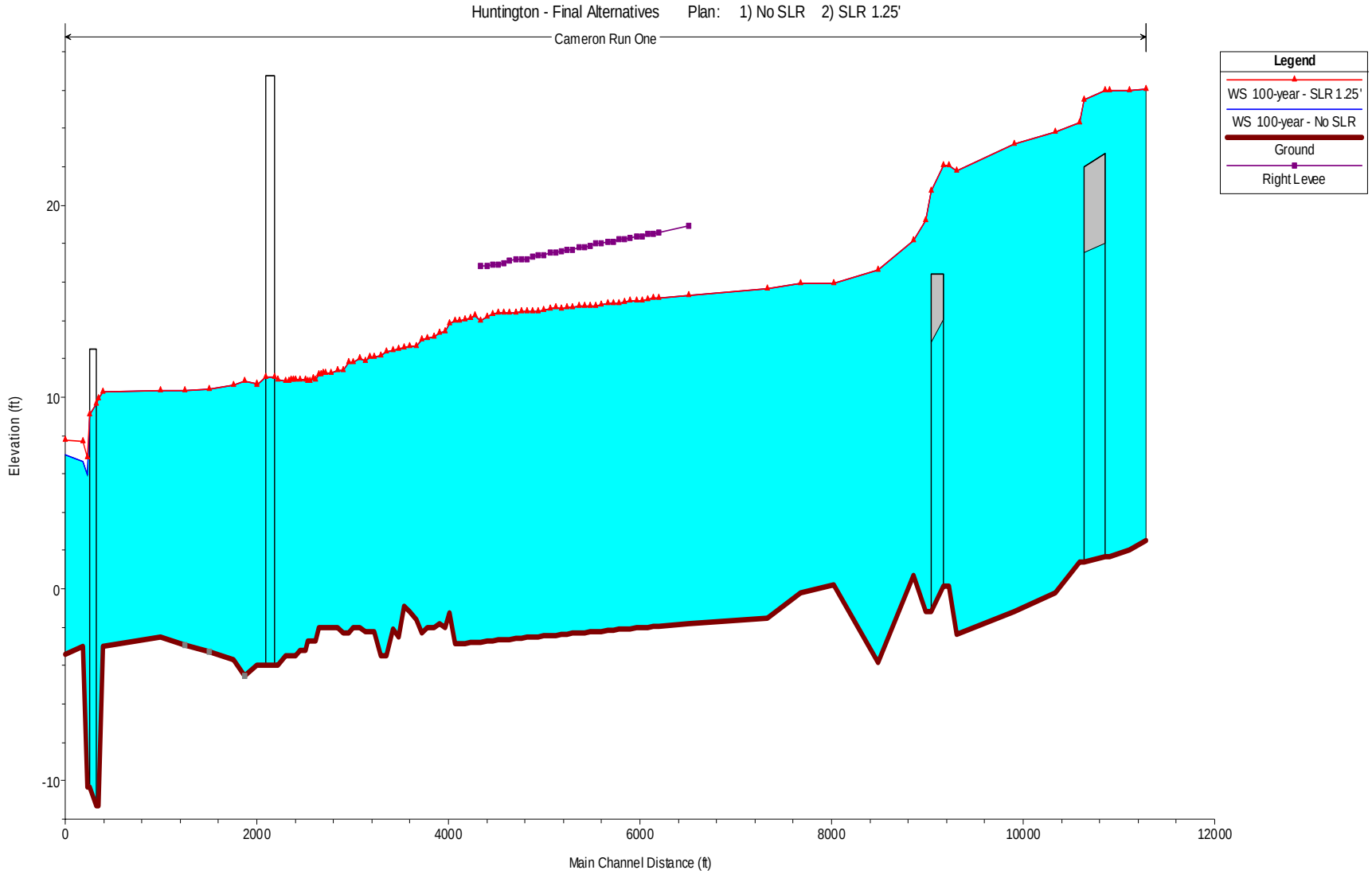

Figure 10. 1% annual chance flood water surface elevation profiles with and without SLR of 1.25 ft in 90 years.

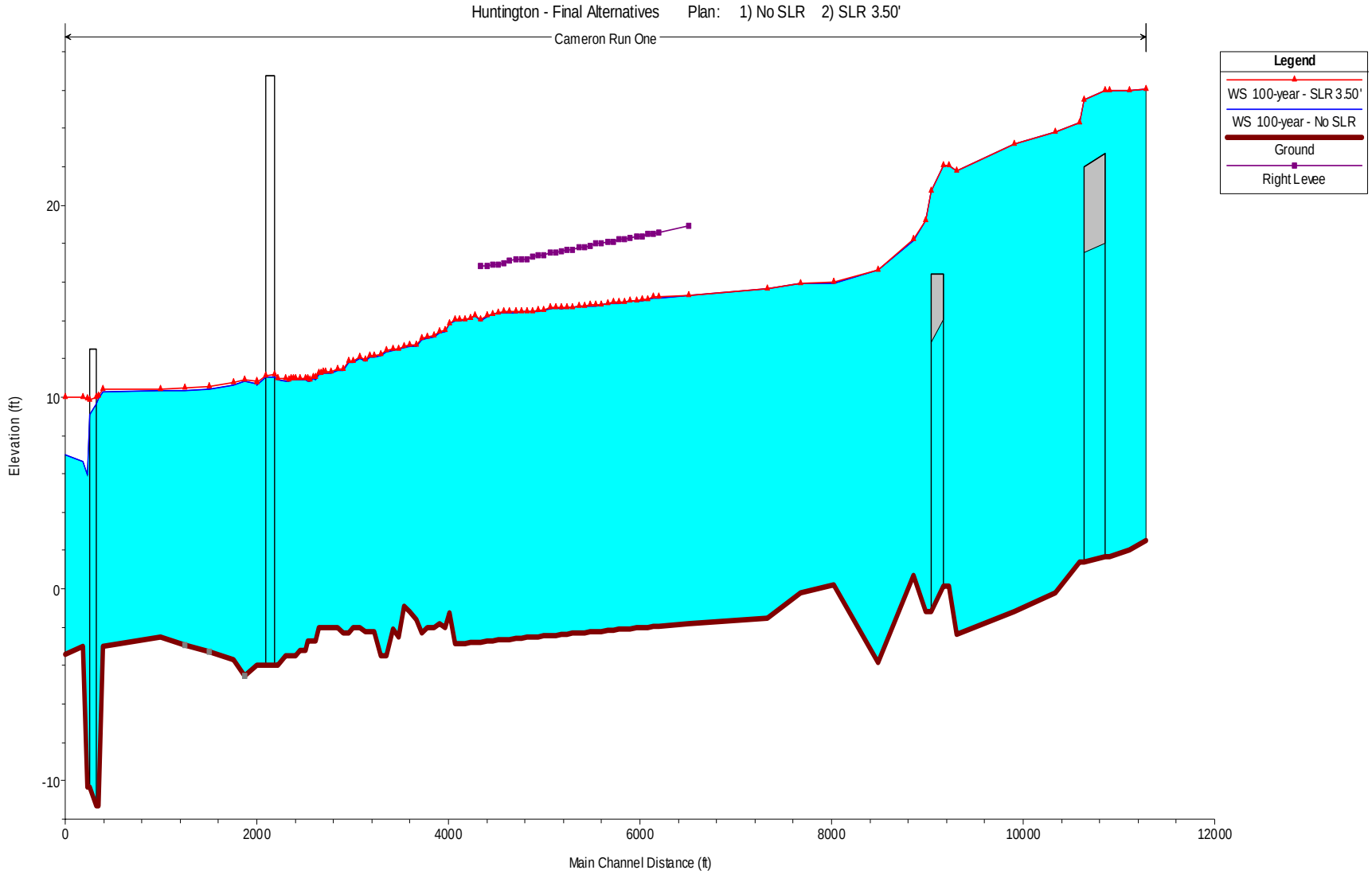

Figure 11. 1% annual chance flood water surface elevation profiles with and without SLR of 3.50 ft in 90 years.