APPENDIX S

INCIPIENT BANK OVERTOPPING ANALYSIS

S Incipient Bank Overtopping Analysis

The elevation at which flow begins to spill out of a channel and into the adjacent floodplain is termed as the incipient bank overtopping elevation. Identification of the incipient bank overtopping elevation for a cross section allows for the calculation of the maximum discharge that can be contained within the channel, referred to hereafter as the incipient bank overtopping discharge. Discharges in excess of the incipient bank overtopping discharge flood overbank areas and allow natural levee building and overbank sedimentation within the floodplain. An incipient bank overtopping analysis was conducted to determine the incipient bank overtopping elevations and discharges for the streams within the study area. The methods used to determine the incipient bank overtopping discharge for each detailed study reach, with the results of the analysis, and interpretation of the significance of the results are presented in the following sections.

S.1 Methodology

The incipient bank overtopping elevations were identified based upon a visual inspection of surveyed channel and overbank geometry data. Significant breaks in slope within each cross section between the channel banks and floodplains were considered to define the incipient bank overtopping elevation. Figure S-1 displays an example assignment of bank overtopping elevations. The orange squares in the figure represent the incipient bank overtopping elevation for the bank on which the square is located. The incipient bank overtopping elevations were determined for both the left and right side of each cross section on each stream within the study area. If the left and right incipient bank overtopping elevations differed by more than 1.5 feet, the lesser of the two was identified as the incipient bank overtopping elevation for that cross section. If the difference was less than 1.5 feet, the average of the two values was used as the incipient bank overtopping elevation for that cross section. While the identification of the incipient bank overtopping elevation at many of the cross sections was generally straightforward, a few cross sections required judgment to identify the incipient bank overtopping elevation. For example, slumping of a channel bank results in more than one location where breaks in slope occur (Figure S-2). However, investigation of the immediate and surrounding areas using aerial photos and cross section data was conducted to allow recognition of slumps and the identification of appropriate incipient bank overtopping elevation estimates.

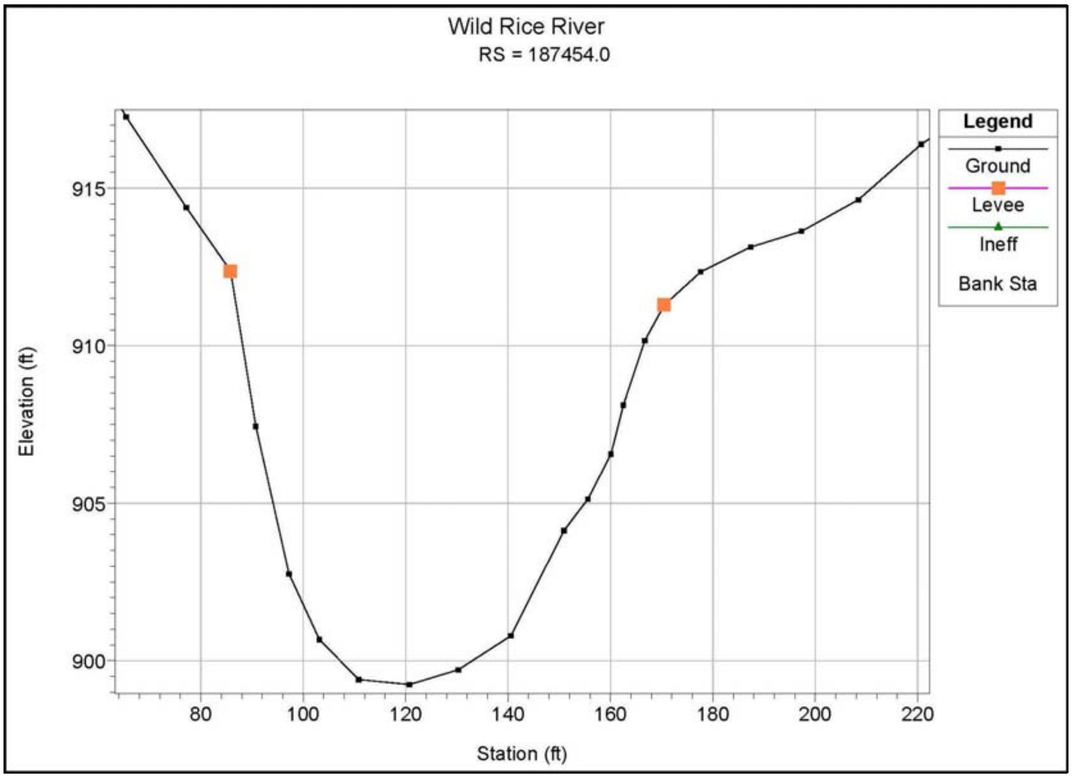

Figure S-1. Definition of Incipient Bank Overtopping Elevation Based on Slope Break

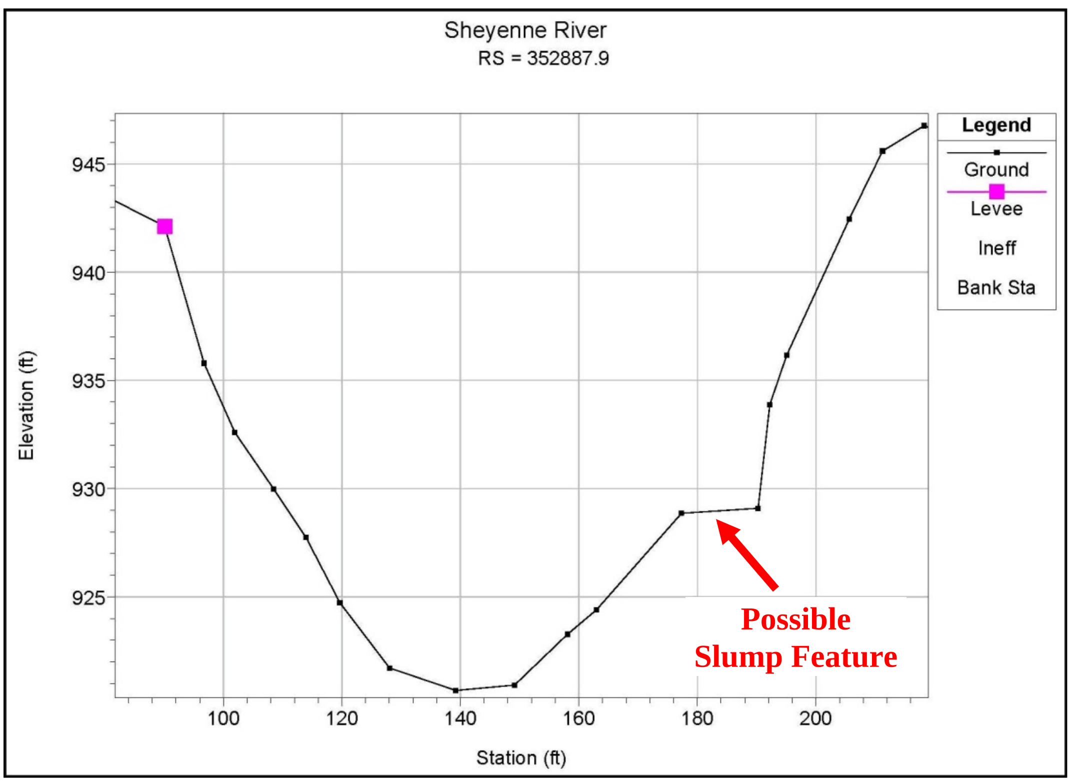

Figure S-2. Possible Slump Feature Example

In order to estimate the incipient bank overtopping discharge for each of the streams, the calibrated steady flow HEC-RAS models developed for the elevation-duration analyses (see Section 4.4.2) were used. The models were used to calculate water surface profiles for each stream over a wide range of discharges represented by the discharge-duration curves. Water surface elevations defined for each of the flow-duration curve discharges were compared to the incipient bank overtopping elevation at each cross section (input as levees at the ground surface in HEC-RAS). The difference between the two values at each cross section was then calculated. The total elevation difference for all of the cross sections was calculated for each discharge. The discharge with the smallest total elevation difference was selected as the representative incipient bank overtopping discharge for that stream. To assess the variability of the incipient bank overtopping elevations from the representative incipient bank overtopping discharge, the discharge profiles bounding the entire set of incipient bank overtopping elevations for each stream was also determined. The discharges bounding the high and low incipient bank overtopping elevations are termed as the high and low incipient bank overtopping discharges, respectively.

It is noted that one change was made to the elevation-duration HEC-RAS models for the incipient bank overtopping analysis. The downstream boundary conditions for the incipient bank overtopping models were changed from a fixed downstream water surface elevation to a normal depth calculation based on channel slope. This boundary condition change was necessary to facilitate a more accurate calculation of the incipient bank overtopping discharge as it was recognized that backwater from the downstream watercourses resulted in water surface profiles that did not correspond well with the identified incipient bank overtopping elevations. An example of the impact of changing the downstream boundary condition from a fixed water surface elevation to a normal depth calculation is shown in Figure S-3. As seen in the figure, the normal depth water surface profile better represents the identified incipient bank overtopping elevations, symbolized as levees in the figure.

Once the representative, high, and low incipient bank overtopping discharges were determined, the recurrence intervals for each of the discharges were determined. The recurrence intervals of the incipient bank overtopping discharges were determined using the same method used to determine the channel-forming discharge recurrence intervals, as discussed in Section 4.2.3.

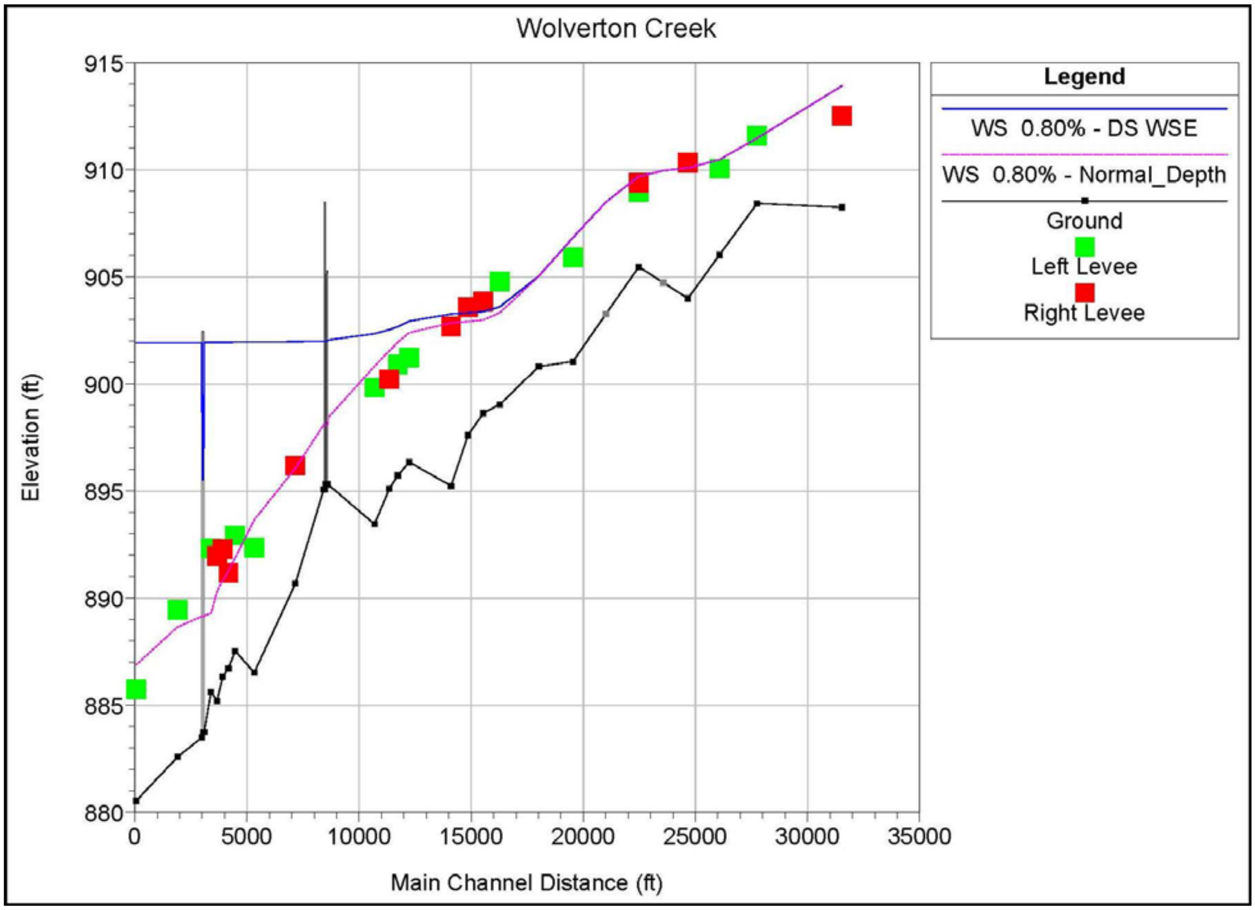

Figure S-3. Comparison of Downstream Boundary Condition Effects on WSE Profiles

S.2 Results

The HEC-RAS profile plots with the discharges that were selected as the representative, high, and low incipient bank overtopping discharges are shown in Figure S-4 through Figure S-12. The elevation points used to define the incipient bank overtopping elevations are symbolized with green and red squares, representing left and right levees, respectively. Notable deviations from the methodology outlined above were needed for three of the study streams. First, the incipient bank overtopping elevations for cross sections downstream of station 20957.46 on the Lower Rush River and station 23098.76 on the Rush River were not considered when determining the representative, high, and low incipient bank overtopping discharges due to the artificial nature of these elevations. The artificially-high incipient bank overtopping elevations are believed to be due to channelization, which has occurred to accommodate the water surface elevation of the Sheyenne River (due to backwater) rather than the flow in the channel. Second, accurate water surface elevations could not be determined for general study reach Sheyenne River – 5 due to missing structure data in the HEC-RAS model and the fact that the water surface elevations within this study reach are impacted by the operation of the gated structure located at the downstream end of the study reach. Therefore, incipient bank overtopping discharge could not be determined for this reach. Third, separate incipient bank overtopping discharges were estimated for the Sheyenne River reaches 1-6 (excluding reach 5) and reaches 7-8. Reaches 7-8 have greater channel capacities than reaches 1-4 and 6. Further discussion regarding this finding is provided in Section S.3.

The recurrence interval (RI) for each representative, high, and low incipient bank overtopping discharge at each detailed study reach is shown in Table S-1. It is noted that the high and representative incipient bank overtopping discharges for Sheyenne River – 7 – 43.27 is less than the same flow for Sheyenne River – 8 – 55.75, which is counterintuitive to the notion that flows increase moving downstream. The cause of the decrease of flows in the downstream direction is that flow breaks away from the main channel between Sheyenne River – 8 – 55.75 and Sheyenne River – 7 – 43.27 and does not pass through the Sheyenne River – 7 – 43.27 detailed study reach (personal communication with Daniel Reinartz, St. Paul District, December 14, 2011). The stream-averaged incipient bank overtopping discharge and previously estimated channel-forming discharge recurrence intervals are compared in Table S-2.

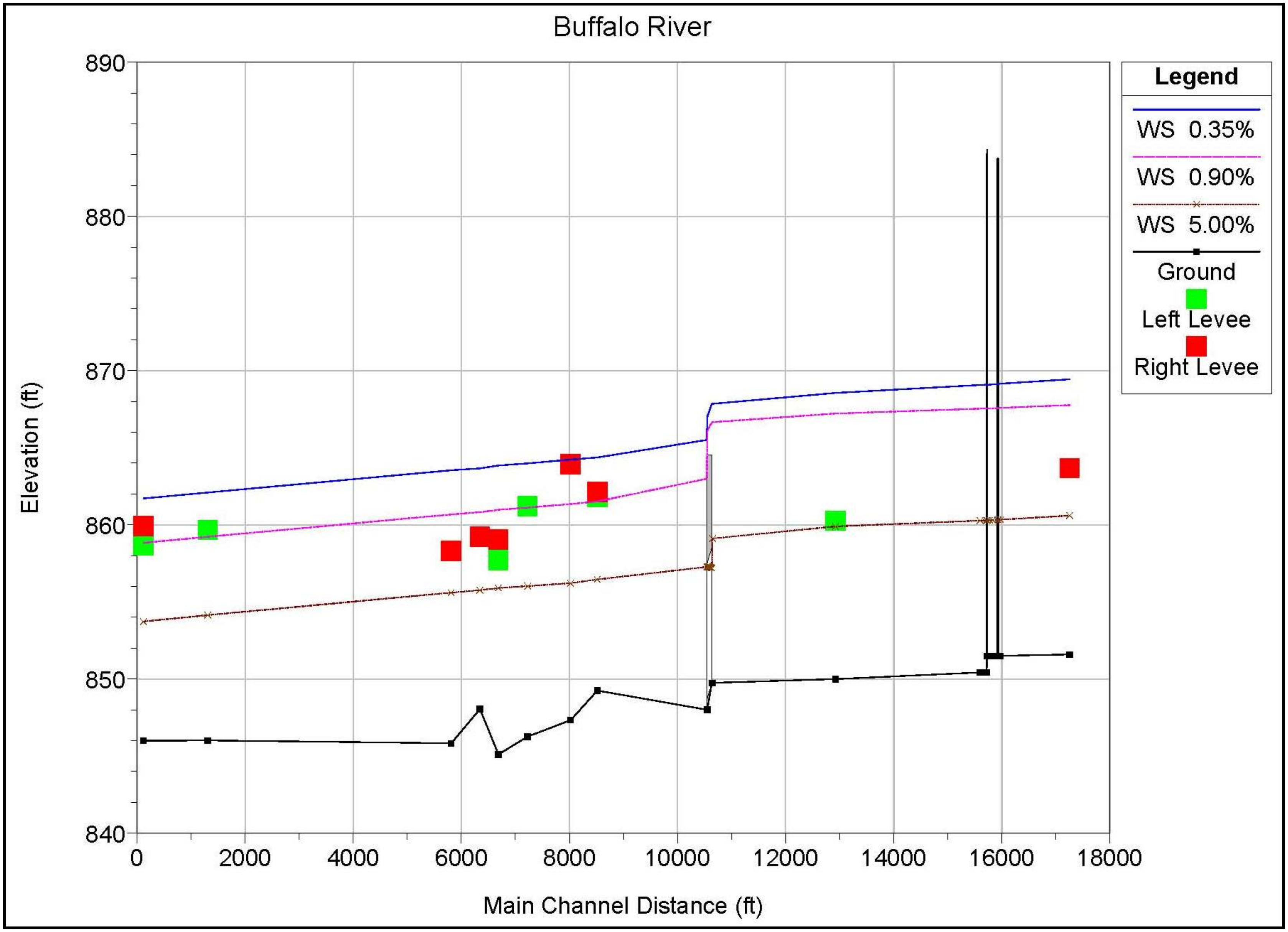

Figure S-4. Buffalo River Incipient Bank Overtopping Elevations

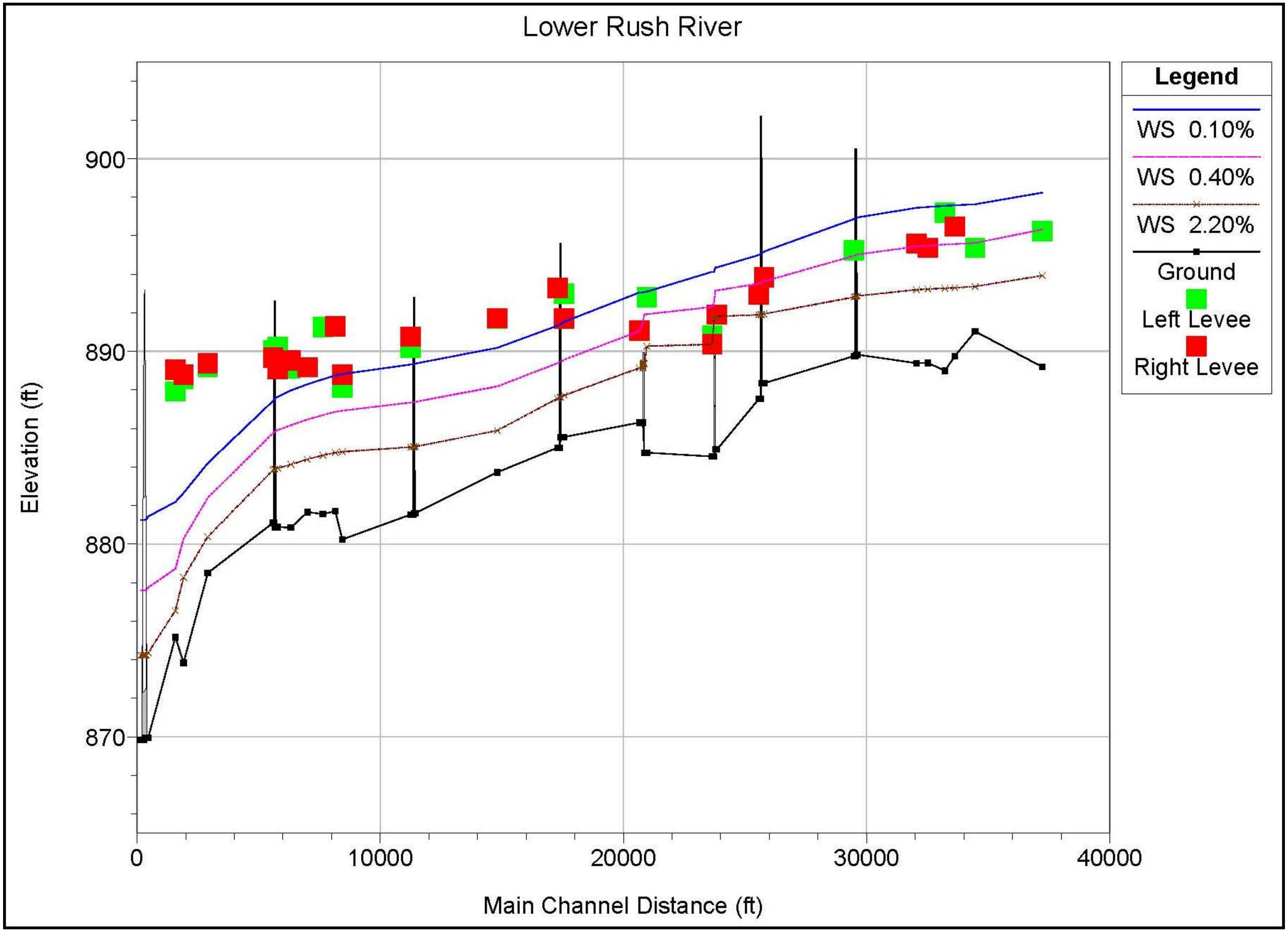

Figure S-5. Lower Rush River Incipient Bank Overtopping Elevations

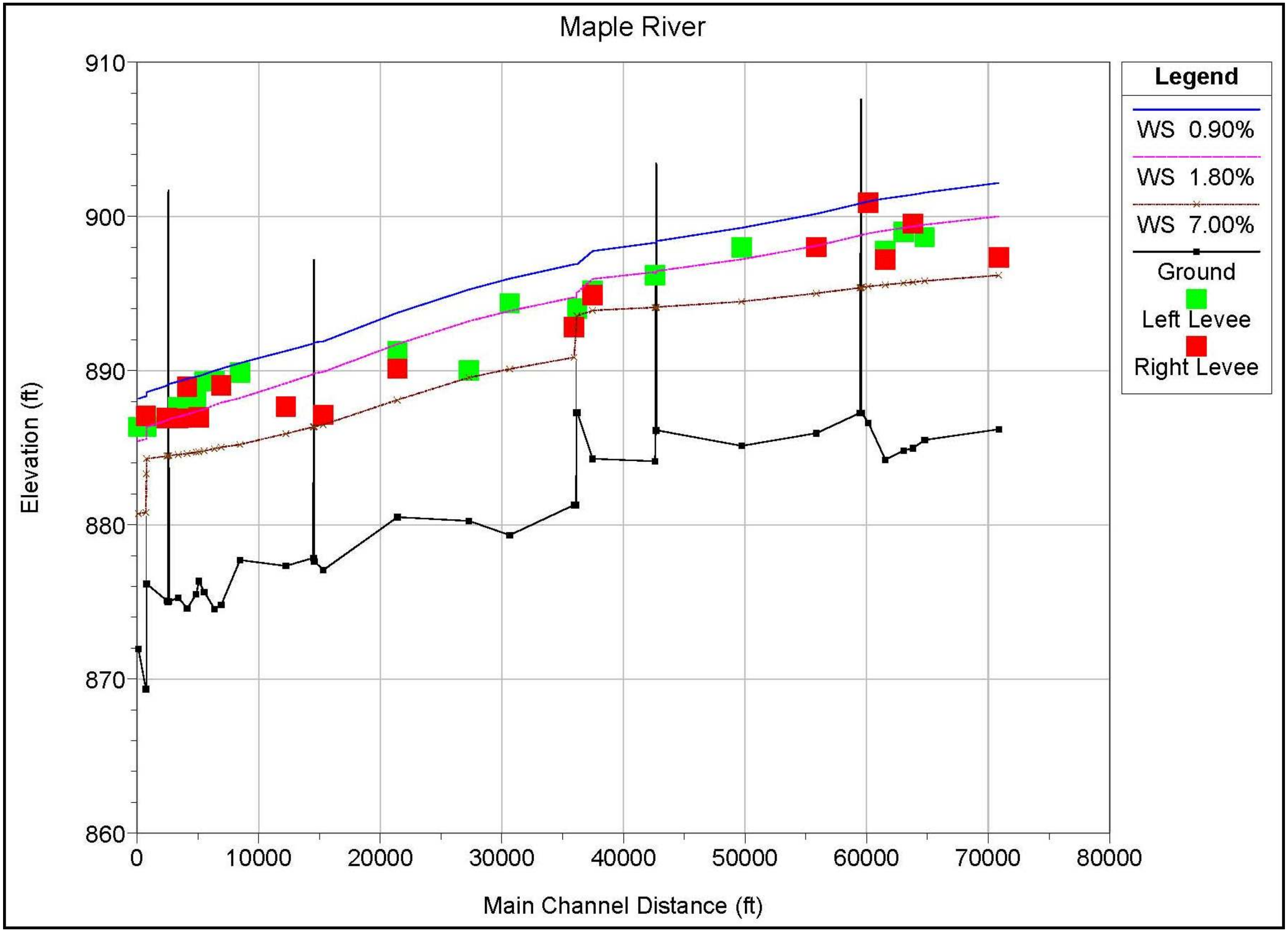

Figure S-6. Maple River Incipient Bank Overtopping Elevations

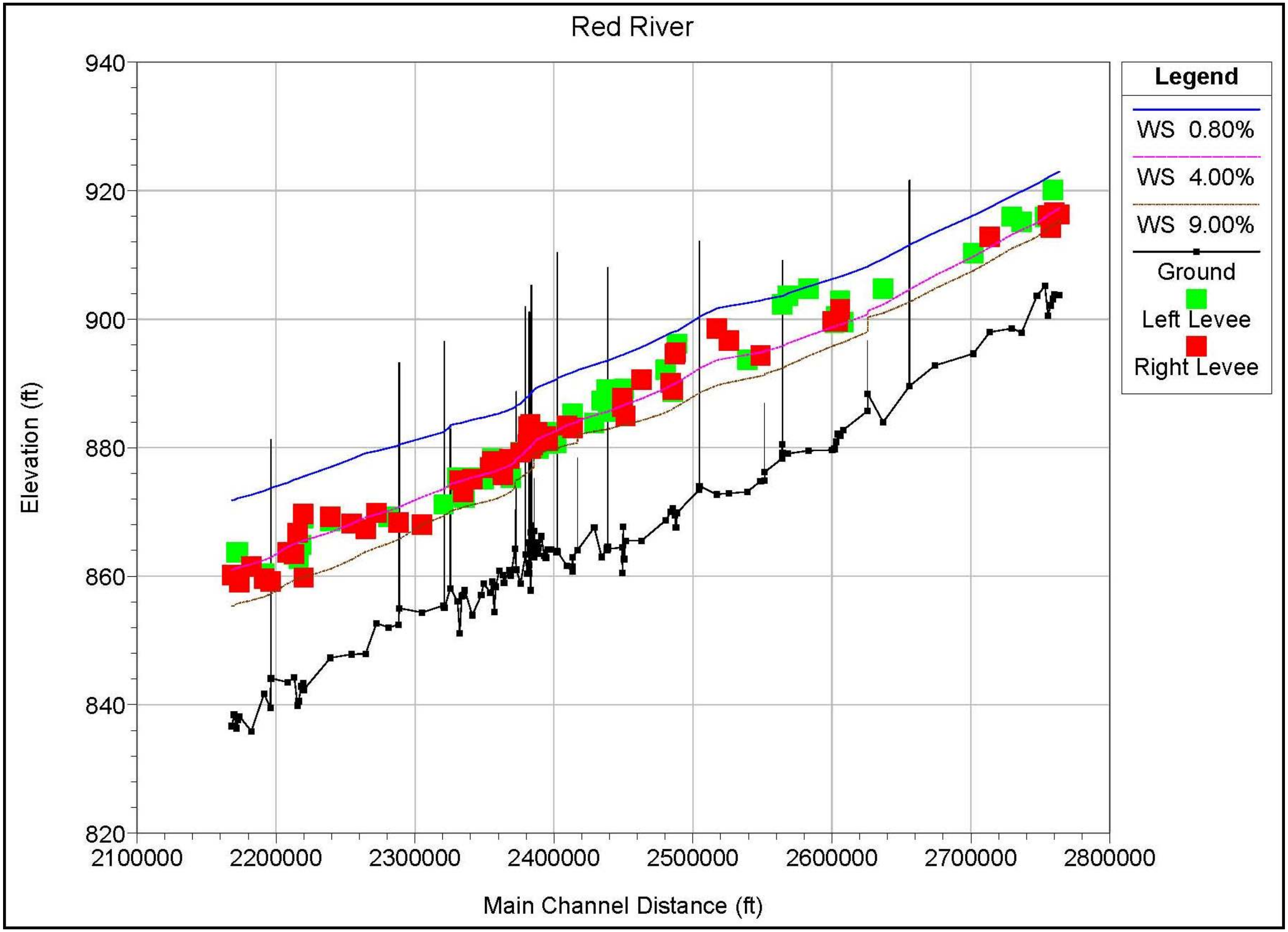

Figure S-7. Red River Incipient Bank Overtopping Elevations

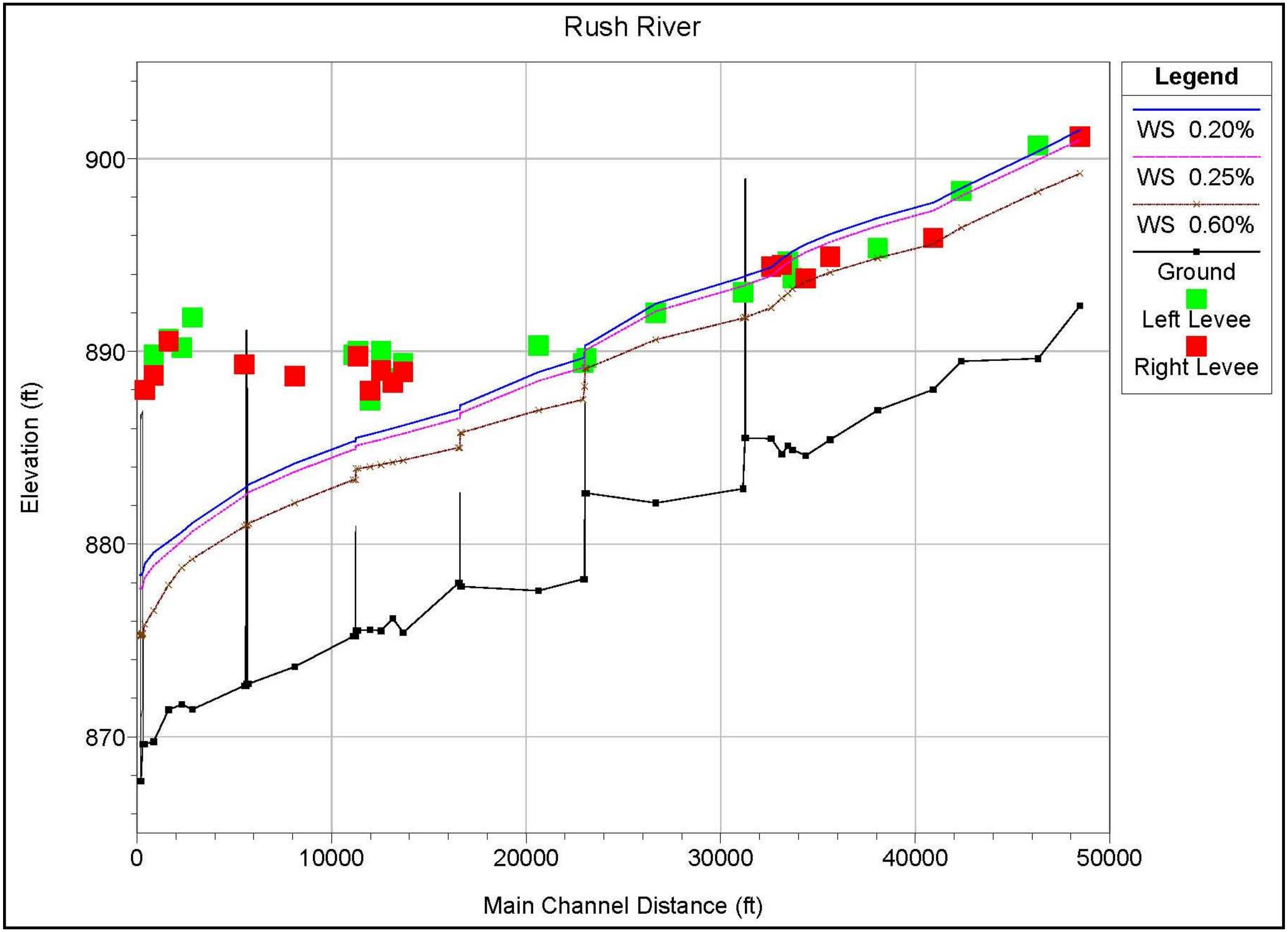

Figure S-8. Rush River Incipient Bank Overtopping Elevations

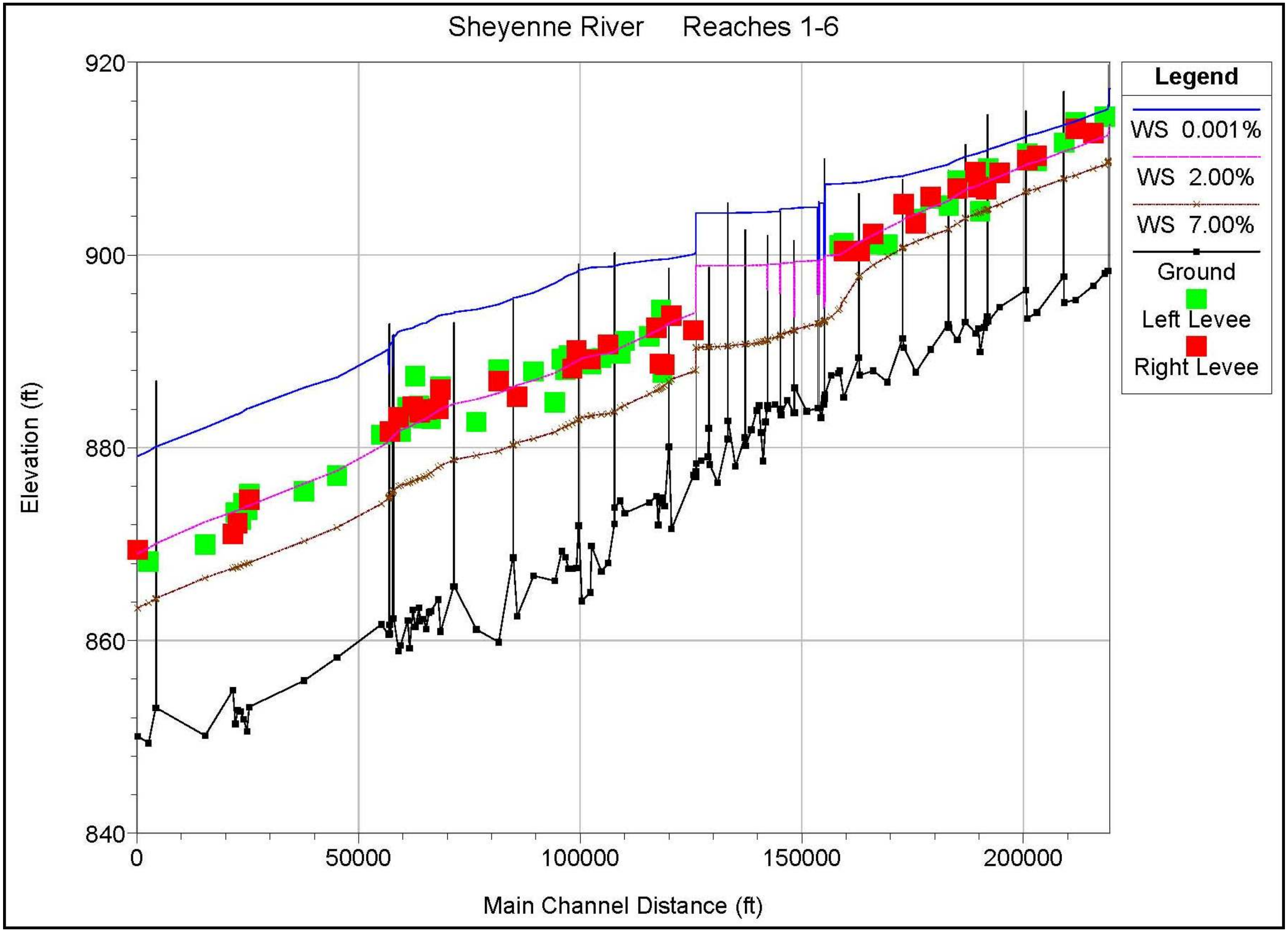

Figure S-9. Sheyenne River (Reaches 1-4 and 6) Incipient Bank Overtopping Elevations

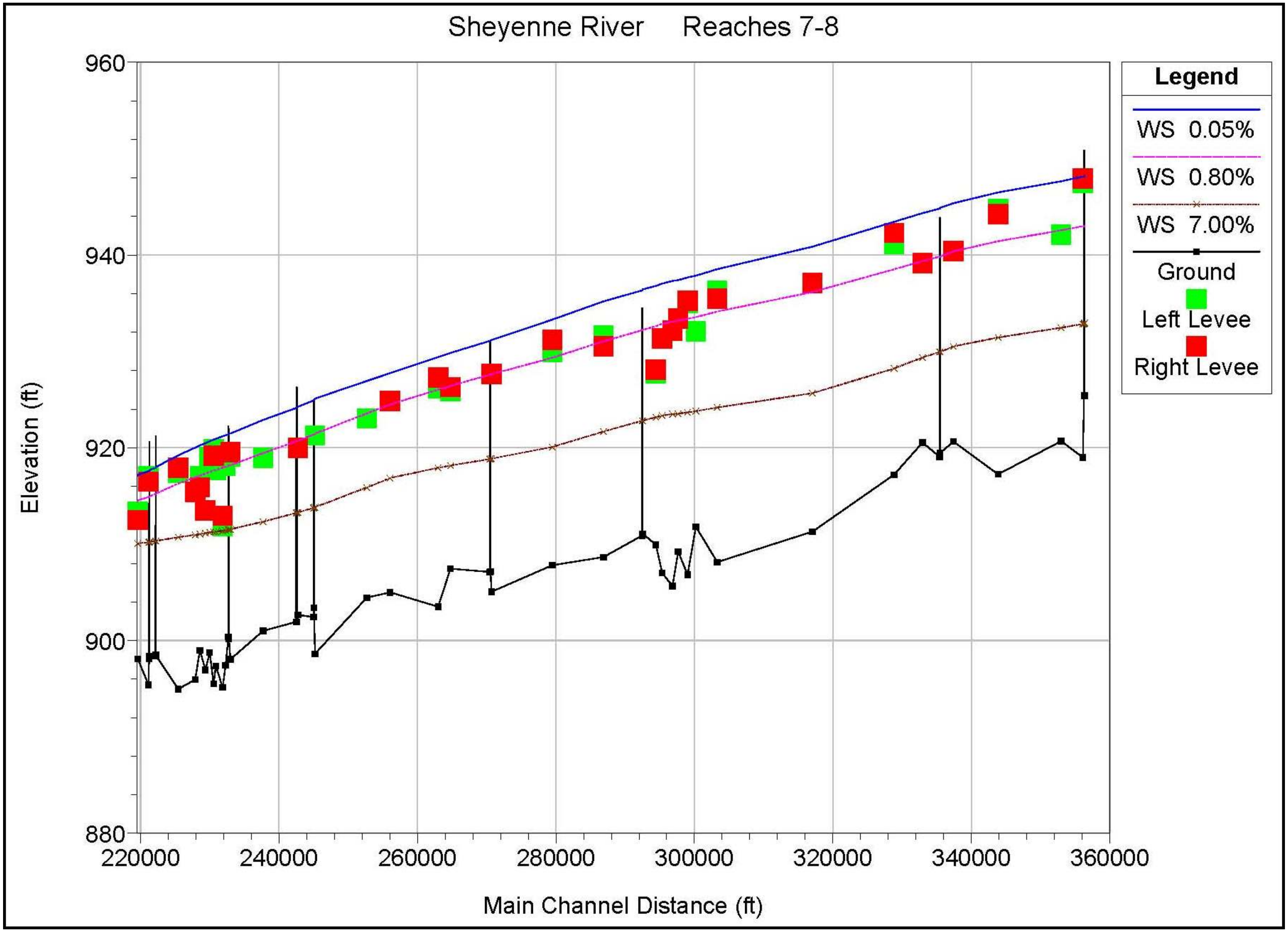

Figure S-10. Sheyenne River (Reaches 7-8) Incipient Bank Overtopping Elevations

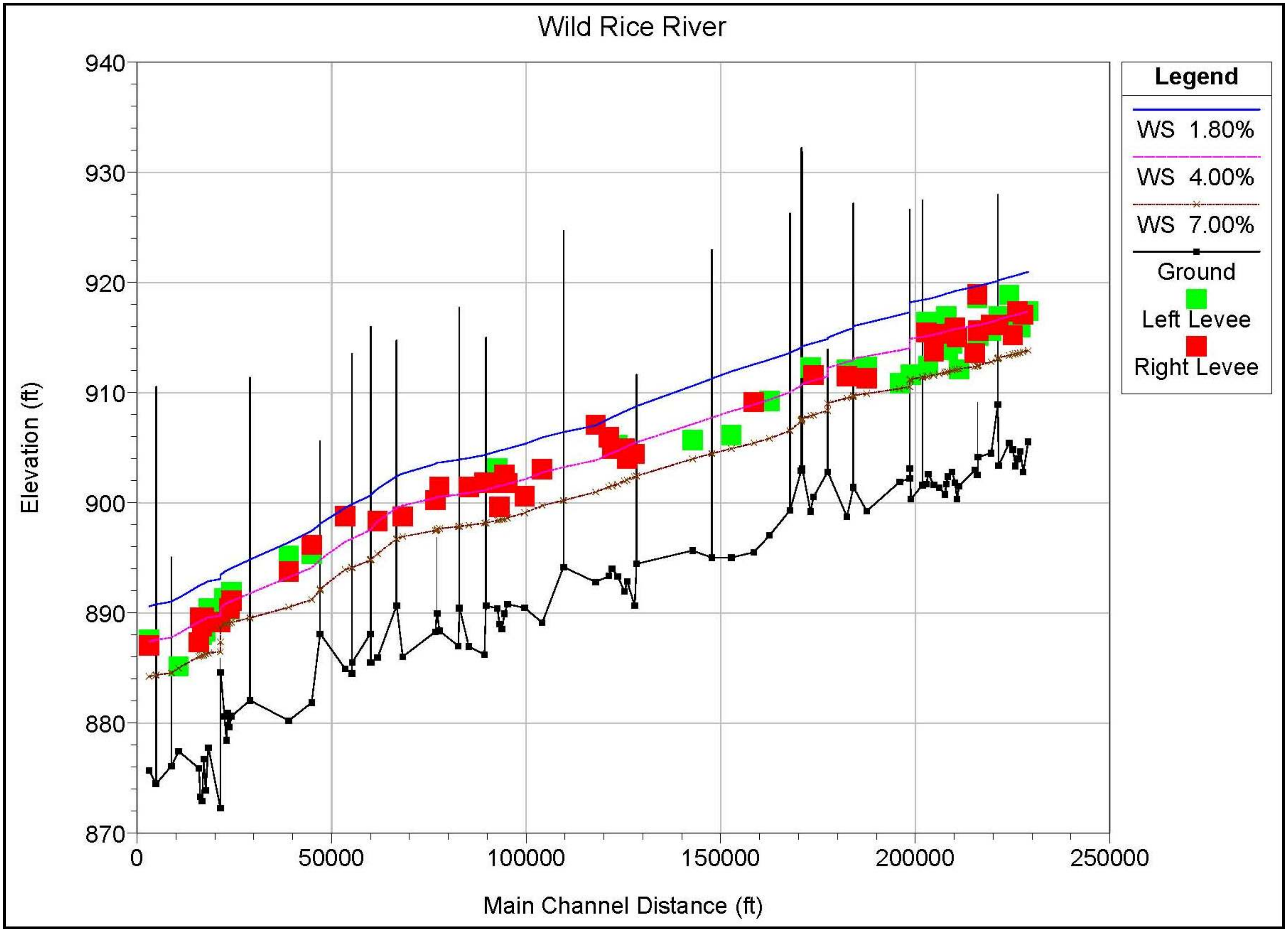

Figure S-11. Wild Rice River Incipient Bank Overtopping Elevations

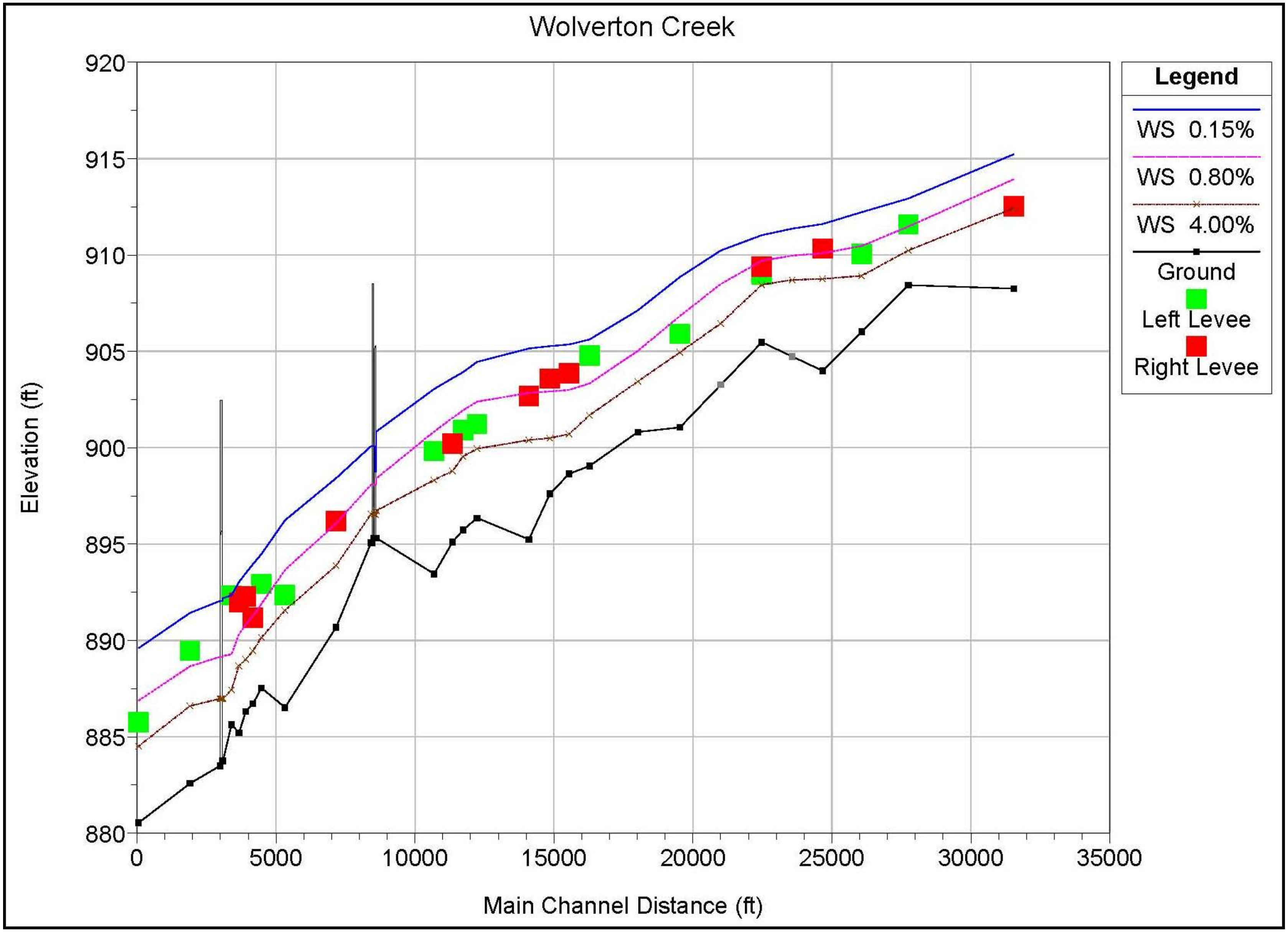

Figure S-12. Wolverton Creek Incipient Bank Overtopping Elevations

Table S-1. Incipient bank overtopping discharges

Detailed Study Reach	Representative Discharge (cfs)	RI (yrs)	High Discharge (cfs)	RI (yrs)	Low Discharge (cfs)	RI (yrs)
Buffalo River-1-1.19	2,425	2.2	3,860	3.7	851	1.2
Lower Rush River-1-1.10	266	2.0	567	4.3	75	1.2
Lower Rush River-2-6.03	239	1.9	509	3.9	68	1.2
Maple River-1-0.78	1,837	1.8	2,772	2.5	778	1.2
Maple River-2-11.39	1,809	1.7	2,729	2.4	766	1.2
Red River-1-410.65	9,511	1.7	23,139	5.5	5,026	1.2
Red River-2-419.14	8,531	1.7	20,779	5.3	4,542	1.2
Red River-3-440.57	4,296	1.7	10,587	4.0	2,448	1.3
Red River-4-452.52	4,260	1.7	10,500	4.0	2,430	1.3
Red River-5-463.56	4,189	1.7	10,287	4.0	2,410	1.3
Red River-6-470.23	2,943	1.5	6,567	4.1	2,068	1.3
Red River-7-492.47	2,841	1.5	6,286	4.1	2,028	1.3
Red River-8-521.18	2,746	1.5	6,075	4.0	1,960	1.3
Rush River-1-0.08	912	3.2	1,029	3.6	548	2.1
Rush River-2-6.15	821	3.0	927	3.4	493	2.0
Sheyenne River-1-4.20	4,652	2.6	14,061	37.5	2,107	1.5
Sheyenne River-2-11.56	4,430	2.6	13,207	37.5	1,999	1.5
Sheyenne River-3-18.15	4,269	2.6	12,589	37.5	1,921	1.5
Sheyenne River-4-22.27	2,242	3.0	4,810	39.4	937	1.4
Sheyenne River-5-26.47	1/	1/	1/	1/	1/	1/
Sheyenne River-6-35.82	1,552	3.9	2,222	2/	960	1.5
Sheyenne River-7-43.27	3,077	5.2	4,649	42.3	959	1.5
Sheyenne River-8-55.75	3,616	7.3	5,920	2/	952	1.5
Wild Rice River-1-3.01	1,151	1.7	2,116	2.4	563	1.3
Wild Rice River-2-4.23	1,151	1.7	2,115	2.4	563	1.3
Wild Rice River-3-17.52	1,127	1.7	2,072	2.4	552	1.3
Wild Rice River-4-22.94	1,091	1.7	2,005	2.4	534	1.3
Wild Rice River-5-38.49	1,060	1.7	1,949	2.4	519	1.3
Wild Rice River-6-42.36	1,050	1.7	1,930	2.4	514	1.3
Wolverton Creek-1-0.64	299	1.5	756	2.9	100	1.1
Wolverton Creek-2-2.02	288	1.5	727	2.8	96	1.1
Median	**-**	**1.7**	**-**	**3.9**	**-**	**1.3**
Minimum	**-**	**1.5**	**-**	**2.4**	**-**	**1.1**
Maximum	**-**	**7.3**	**-**	**2/**	**-**	**2.0**

1/ Discharge could not be determined.

2/ Discharge is greater than the 500-year recurrence interval peak discharge.

Table S-2. Average Discharge Recurrence Interval (RI) Comparisons

Stream	Representative Incipient Bank Overtopping Discharge RI	High Incipient Bank Overtopping Discharge RI	Low Incipient Bank Overtopping Discharge RI	Channel-Forming Discharge RI
Buffalo River	2.2	3.7	1.2	1.0
Lower Rush River	2.0	4.1	1.2	1.1
Maple River	1.8	2.4	1.2	1.2
Red River	1.6	4.3	1.3	1.2
Rush River	3.1	3.5	2.1	1.2
Sheyenne River 1-4 and 6	3.0	38.0[1/]	1.5	1.4
Sheyenne River 7-8	6.2	42.3[2/]	1.5	1.6
Wild Rice River	1.7	2.4	1.3	1.3
Wolverton Creek	1.5	2.9	1.1	1.1

[1/] Excludes values for Reaches 5 and 6.

[2/] Excludes value for Reach 8.

S.3 Discussion of Results

In general, the representative incipient bank overtopping discharge recurrence intervals are moderately larger than the recurrence intervals calculated for the channel-forming discharges. However, the representative incipient bank overtopping discharge recurrence intervals for Sheyenne River general study reaches 7 and 8 are considerably larger than the recurrence intervals calculated for the channel-forming discharges. This is likely due to the high proportion of sand-sized sediment carried in suspension in the Sheyenne River. The source of this sand is the historic glacial Lake Agassiz beach deposits located just upstream of the study area (see Figure 2-2). As the sand-sized sediment is transported downstream from the source area, any sediment that is transported in suspension into the adjacent floodplain settles out of the flow and is deposited along the top of the channel bank (see Figure S-13) due to a sudden reduction in sediment transport capacity. Over time, the incipient bank overtopping elevation increases creating additional channel capacity. The supply of sand decreases in the downstream directions, reducing the rate of natural levee formation as the river flows further away from the sand source. Additionally, flow is diverted at the upstream end of Sheyenne River – 6 via the Horace Diversion, lessening the frequency of bank overtopping flows downstream of the Horace Diversion. For these reasons, natural levee building is occurring at a slower rate in Reaches 1-4 and 6 compared to Reaches 7-8. This is reflected by the relatively smaller incipient bank overtopping discharges for Sheyenne River general study reaches 1-4 and 6.

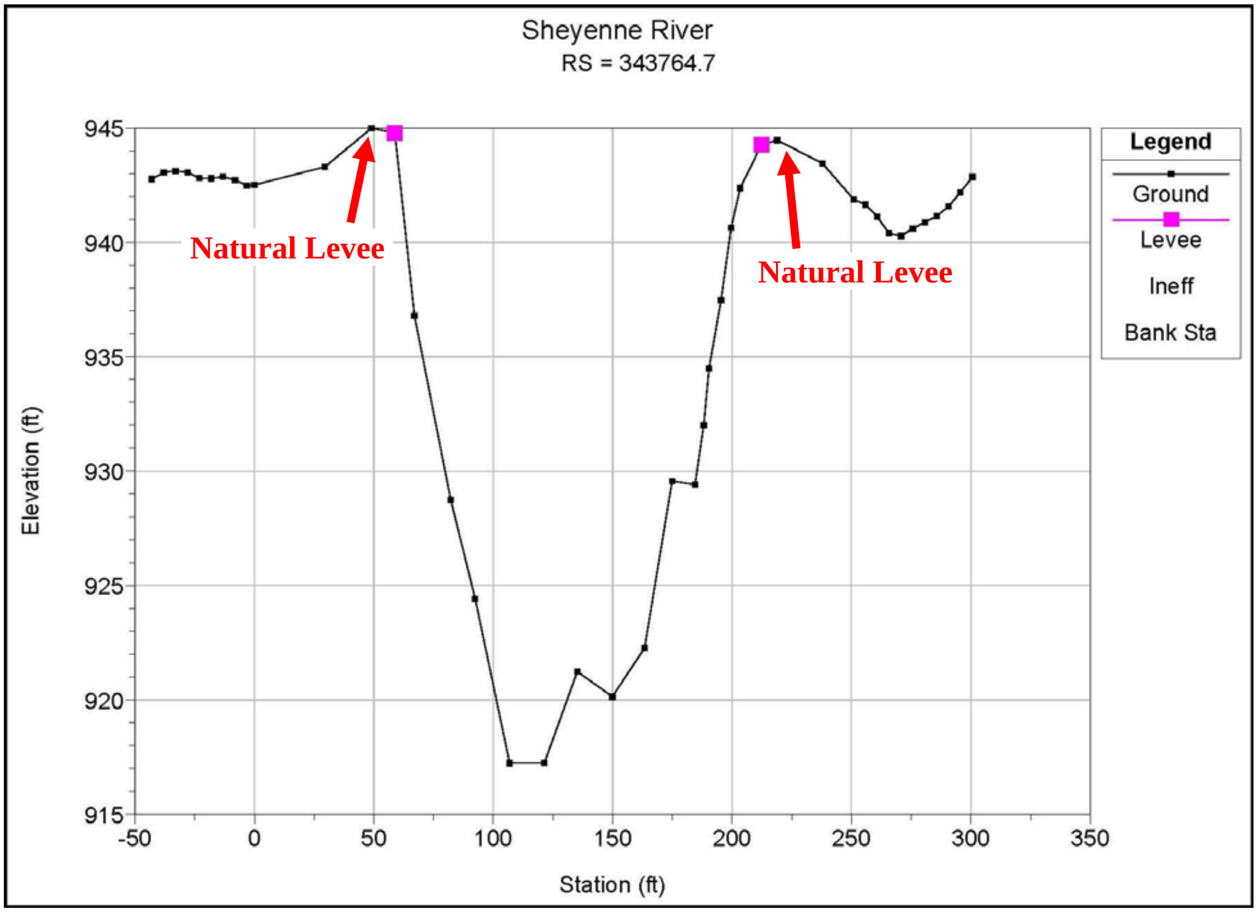

Figure S-13. Natural Levee Building Example in Sheyenne River – 8

The range between the high and low bounding incipient bank overtopping discharges provides an indication in the variability of the incipient bank overtopping elevation throughout the stream. The Sheyenne River exhibits a large variation between the low and high incipient bank overtopping discharge recurrence intervals. The remaining streams exhibit differences of no greater than 3.1 years. This is again the result of the sand-sized material transported in suspension. The deposited material forms natural levees alongside the Sheyenne River in some spots, thereby increasing the incipient bank overtopping elevation over time. The silt- and clay-sized channel materials prevalent in the suspended load of the remaining streams do not deposit in the same manner as do the sand-sized materials. The silt- and clay-sized materials have been observed to deposit more evenly throughout the overbank area, minimizing the building of natural levees and thereby minimizing the potential for relatively high incipient bank overtopping elevations.

Both the Red River and Wild Rice River overtop their banks at flows less than the 3.6-year event. Based upon the representative incipient bank overtopping discharge calculated for the Red River and Wild Rice River, the streams would only be able to contain on average the 1.6- and 1.7-year events, respectively. If the 3.6-year discharge is allowed to bypass the diversion, overbank flow will continue to occur in portions of the protected reaches. Natural overbank sedimentation and bank slumping is expected to continue, although likely at moderately reduced rates. Riparian vegetation is also expected to increase in density although not to the extent that would be expected if flows were not allowed to overtop the banks.

The Maple River overtops its banks during flows that have slightly less than the 2-year recurrence interval. Predictions regarding future geomorphic conditions with the protected portions of the Maple River are not expected to change. The Sheyenne River overtops it banks during flows that are significantly greater than the 2-year recurrence interval flow. Predictions regarding future geomorphic conditions with the protected portions of the Sheyenne River are not expected to change.