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Final Hydraulic Design Memorandum

To: Dorie Bolze and Michael Cain (HRWA)
From: Case Davis, P.E. (BCH)
Date: 1/5/2012
Re: Harpeth River Restoration and Dam Removal: Final Hydraulic Design Memorandum

1. Introduction

This memorandum provides a description of the final design for the above referenced project, including stream restoration components, site assessment of the City of Franklin water intake structure, results of hydraulic and sediment transport analyses and design criteria for the size and geometry of natural materials. These results indicate that no modifications of the existing water intake structure will be required. The pool elevation set by the proposed double-invert boulder cross vane will allow withdrawal at all permitted flow rates.

2. Description of the Preliminary Design Plan

The Final Design layout is shown in Figure 1 and highlights stream restoration features at the dam removal site, including: (1) a double-invert boulder cross vane, (2) bankfull bench, (3) wood toe structure, (4) boulder clusters, (5) log cross vanes, (6) log and boulder step-pools. These habitat components are described in more detail below.

2.1. Double-invert boulder cross vane

Water elevation in the vicinity of the City's water intake structure will be controlled after dam removal to maintain a minimum water surface elevation meeting pump submergence criteria described further in paragraph 3.0. Control is established by placement of a double-invert boulder cross vane 130-ft downstream of the existing intake. "The Cross-Vane is a grade control structure that decreases near-bank shear stress, velocity and stream power, but increases the energy in the center of the channel. The structure will establish grade control, reduce bank erosion, create a stable width/depth ratio, maintain channel capacity, while maintaining sediment transport capacity, and sediment competence. The Cross-Vane also provides for the proper natural conditions of secondary circulation patterns commensurate with channel pattern, but with high velocity gradients and boundary stress shifted from the near-bank region." (Rosgen, 2006, Cross-vane, J-hook and W-weir structures, Wildland Hydrology.) Dimensions of the structure are illustrated in Figure 3, along with boulder sizes determined based on shear stresses from hydraulic model simulations of flood flows. Proper construction techniques are critical for the cross vane structure to meet the elevations specified. Construction involves placement of boulders and interstitial mix composed of cobble and gravel to form a glide into the structure and for filling and chinking all voids between boulders and the run downstream of the boulders. Water surface profiles produced by the structure are shown and discussed in paragraph 4.0.

2.2. Bankfull bench

Geomorphic assessments performed by BCH indicate that the project reach is entrenched as defined in Part 654 Stream Restoration Design of the United States Dept. of Agriculture, Natural Resources Conservation Service's (NRCS) National Engineering Handbook. Entrenchment occurs when bank heights exceed the normal high water (bankfull) heights and represents the degree of incision into the valley. Entrenchment is improved to conditions appropriate the C4 stream type (Rosgen, 1996) by the excavation of vegetated bankfull benches in locations identified by green shading in Figure 1 and with geometry shown in Figure 2. The bankfull benches additionally increase flood capacity and decrease shear stresses on the channel bed during flood flows, as discussed further in paragraph 4.0. Further, the bankfull benches allow access trails and points along water's edge for recreation during low flows.

2.3. Toe wood structure

Two lengths of toe wood structure are identified by magenta coloring in Figure 1. The toe wood placement enhances fish habitats and food chains, stabilizes streambanks, maintains a low width/depth ratio, eliminates the need for toe rock, is compatible with the C stream type and is cost effective with lower risk than other bank stabilization techniques (Rosgen 2010). The structure incorporates native woody material into a submerged undercut bank to replicate natural streambanks. The toe wood is positioned on the lower part of the bank so it is submerged to prevent wood deterioration. Native cuttings with sod and live staking or woody transplants cover the toe wood and are installed up to the bankfull stage in soil lifts wrapped with biodegradable coir fabric to provide immediate erosion control and a natural appearance.

2.4. Boulder clusters

Boulder clusters for fisheries improvements are shown in various locations along the channel bed in Figure 1. The purpose of boulder clusters is to promote spatial variation in flow velocity to induce scour pools and to provide fish cover. The spatial configuration shown in Figure 1 is based on BCH's experience and observations over time and is an adaptation of clusters shown in NRCS's Stream Habitat Improvement Handbook (1992).

2.5. Log cross vanes

Three log cross vanes are shown along the channel of the southern tributary in Figure 1. These structures are placed to control bed and bank erosion in the tributary and function similar to the structure described above in paragraph 2.1.

2.6. Log and boulder step-pools

Four log and boulder step-pools are shown along the channel of the northern tributary in Figure 2 in order to step the water level back up to the existing level coming in from off-site. The structures are designed to promote fish passage and to eliminate the potential for head-cutting into the tributary due to dam removal and lowering of base level in the Harpeth River at this location.

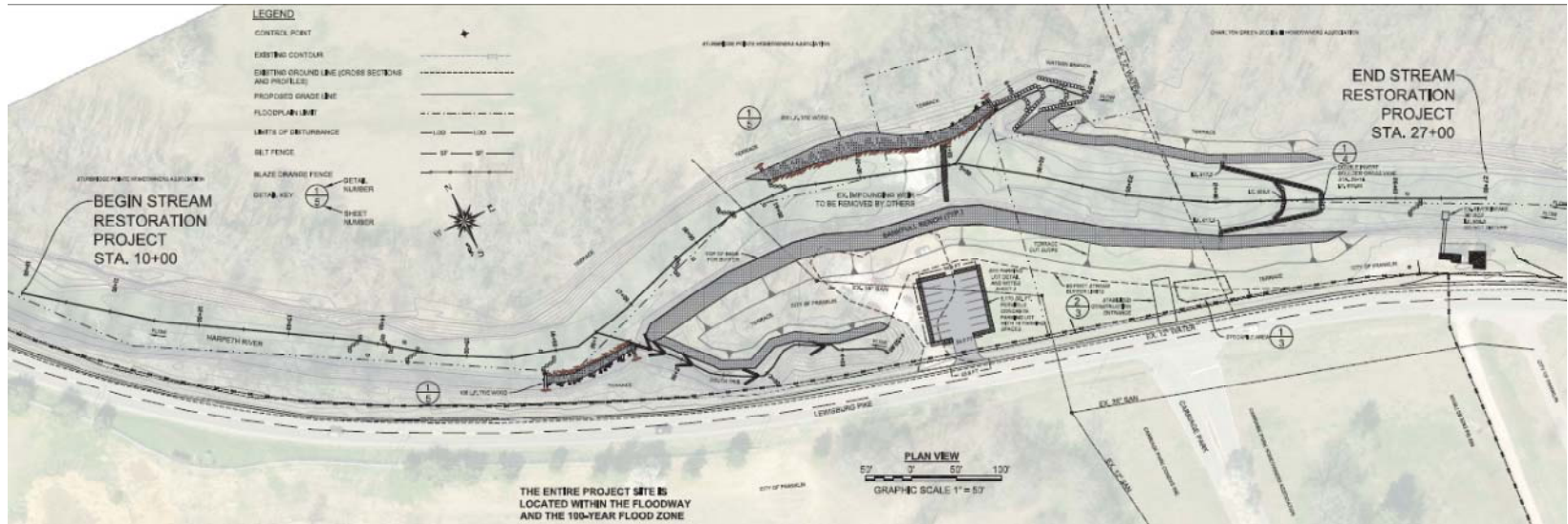


Figure 1. Plan view of the final design, refer to project drawings.

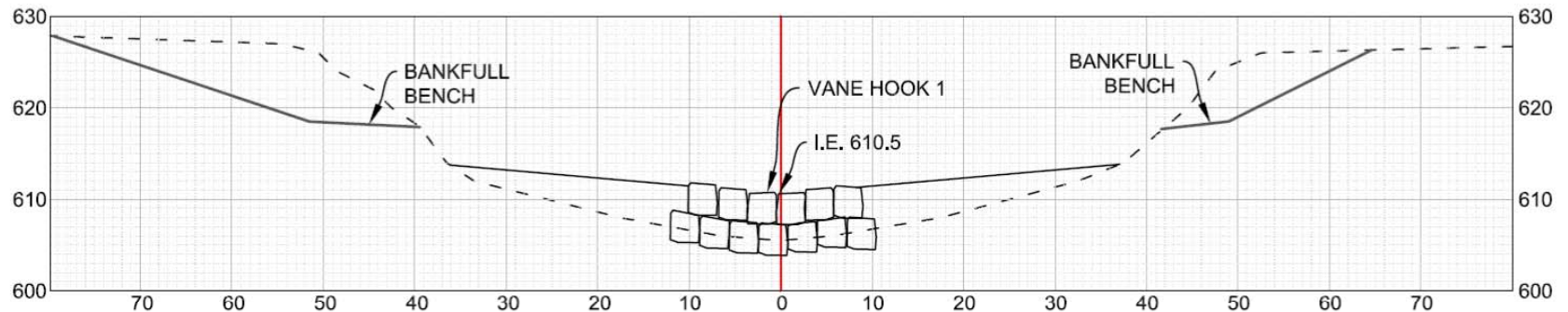


Figure 2. Cross section (see C-C' line in Figure 3) and downstream view of the proposed bankfull benches and channel invert of the vane hook controlling grade at the water intake structure. The red line denotes the location of the channel center. The sloped lines in the channel indicate the surface of compacted interstitial mixture (cobble and gravel).

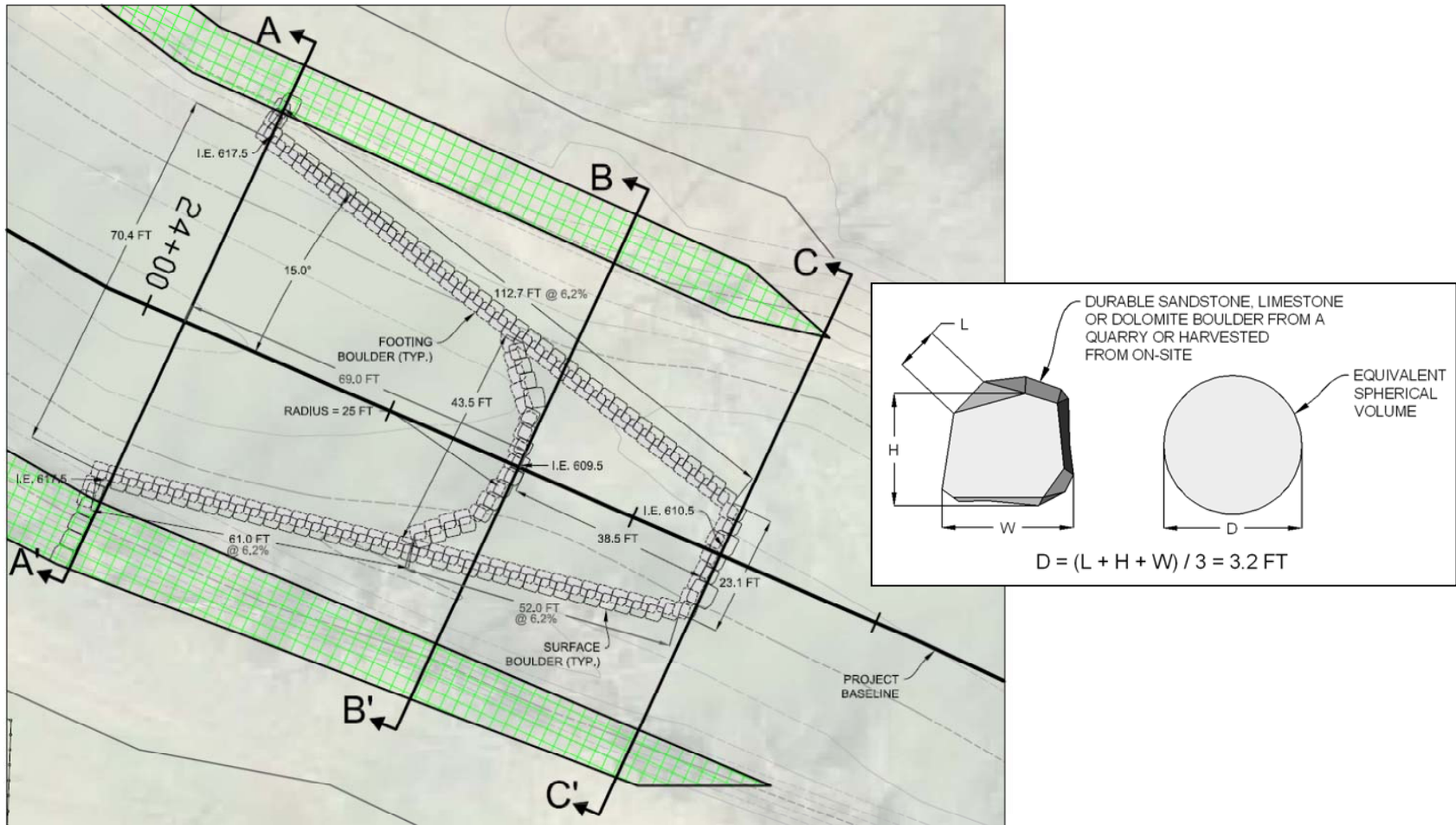


Figure 3. Plan view detail of the proposed double-invert, boulder cross vane for grade control and aquatic habitat. The inset identifies boulder dimensions and materials.

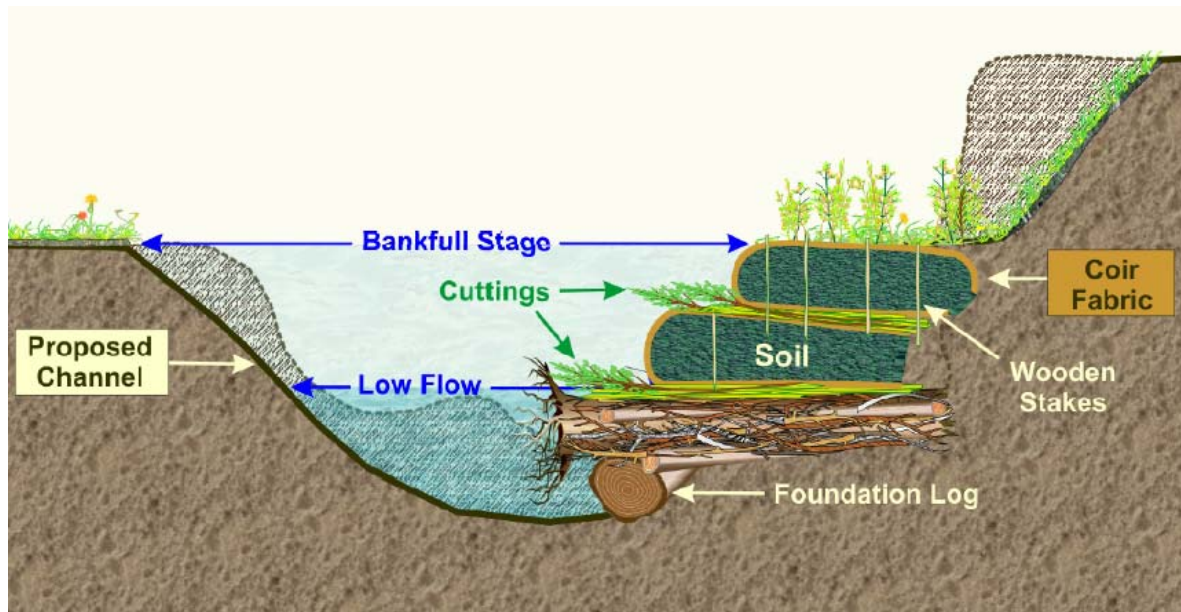


Figure 4. Cross section view of toe wood structure (reprinted with permission from Rosgen, 2010).

3. Analysis of City of Franklin Water Intake Structure

BCH performed a site visit to assess the existing pumping station with representatives from the City of Franklin and HRWA. Technical data regarding the operational conditions of the current pump were field verified and compared to design drawings provided by the City of Franklin, reprinted here in Figure 5. The technical drawings for the existing pumping station show that one pump in the wet well is capable of providing 5,600 gallons per minute (GPM) at full capacity. The floor of the wet well is at elevation 603.75 ft. The inlet to the 14-in diameter pump bell is elevated 12 inches above the floor.

Analysis of the water depths in the wet well followed guidelines provided in ANSI/HI 9.8, 1998, "American National Standard for Pump Intake Design," Hydraulic Institute, Parsippany, New Jersey (ANSI). According to ANSI Section 9.8.2.1.4, a minimum submergence (S) is required to prevent the development of surface vortices which may be detrimental to pump operation. The minimum submergence is defined in equation (1) and is

$$S = D(1 + 2.3F) \quad (1)$$

Where, S = minimum submergence (ft)

D = Outside diameter of bell or pipe inlet (ft)

F =Froude number (dimensionless):

$$F = \frac{V}{\sqrt{gD}} \quad (2)$$

V = Velocity at suction inlet = Flow/Area (ft/s)

g = gravitational acceleration

The elevation that corresponds to the minimum submergence is assumed to be the minimum allowable water surface elevation for the pumping station to prevent strong air-core surface vortices at the inlet that may affect pump operation. The equivalent axial velocity, V , of the pump operating at maximum capacity and assumed to be in reasonable state of repair, is 11.7

feet per second. Froude number, **F**, is 1.9 from equation (2). Minimum submergence, **S**, is 6.28 ft from equation (1) resulting in the minimum allowable water surface elevation of **611.03 ft** ($= 6.28 + 12/12 + 603.75$), as shown in Figure 5.

The schematic of the pumps were removed from the public distribution of this report in accordance with the Homeland Security Act .

Figure 5. Elevation view and detail of the intake facility's pumping station (source: Raw Water Pumping Station design drawings dated 2-28-1958 by Harry Hendon and Associates, sheet 305-09, provided by City of Franklin) with minimum submergence overlay.

4. Hydraulic Modeling of Flows in the Harpeth River

Hydraulic modeling of both existing conditions and for the Preliminary Design conditions (see Fig. 1) were performed using the United States Army Corps of Engineers, Hydrologic Engineering Center’s River Analysis System (HEC-RAS). BCH analyzed water surface profiles, velocities and shear stresses for seven flow rates listed in Table 1, ranging from low flows (10 cfs) to extreme floods (500-year flood flow estimate). The bankfull discharge was determined by hydraulic modeling of topographic survey data collected by BCH. Flood flows were estimated from USGS gage data and a fitted distribution shown in Figure 6. The 500-Year flood flow is estimated as a linear extension of the fitted distribution.

Table 1. Flow Inputs for HEC-RAS Modeling

Profile Name	Flow Rate (cfs)
Low Flow	10
0.5 x Bankfull Discharge	1,584
Bankfull Discharge	3,167
1.5 x Bankfull Discharge	4,751
Two-Year Flood Flow	8,640
100-Year Flood Flow	25,061
500-Year Flood Flow	36,000

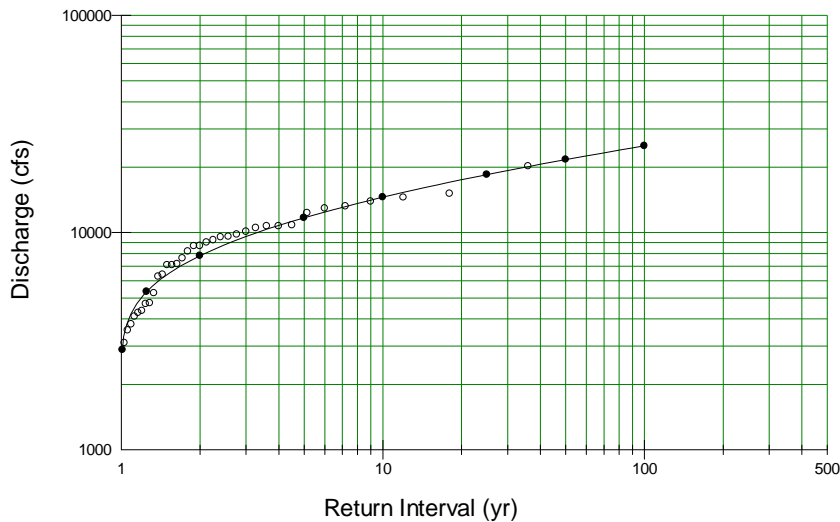


Figure 6. Gage 03432350 on the Harpeth River downstream of the project site. The open circles are data collected by USGS, the solid circles and black line represent a Log-Pearson Type III flood frequency model fitted by BCH.

Water surface profiles which result from the hydraulic model runs simulating existing conditions and as-built stream restoration components are shown below in Figs. 7 and 8. The results show that the water surface at the water intake facility (channel distance 2,100) is at an elevation 611 ft at low flow, meeting the minimum submergence criteria identified in Fig. 5. The elevation of the proposed bankfull bench coincides with the bankfull water surface in Figure 8.

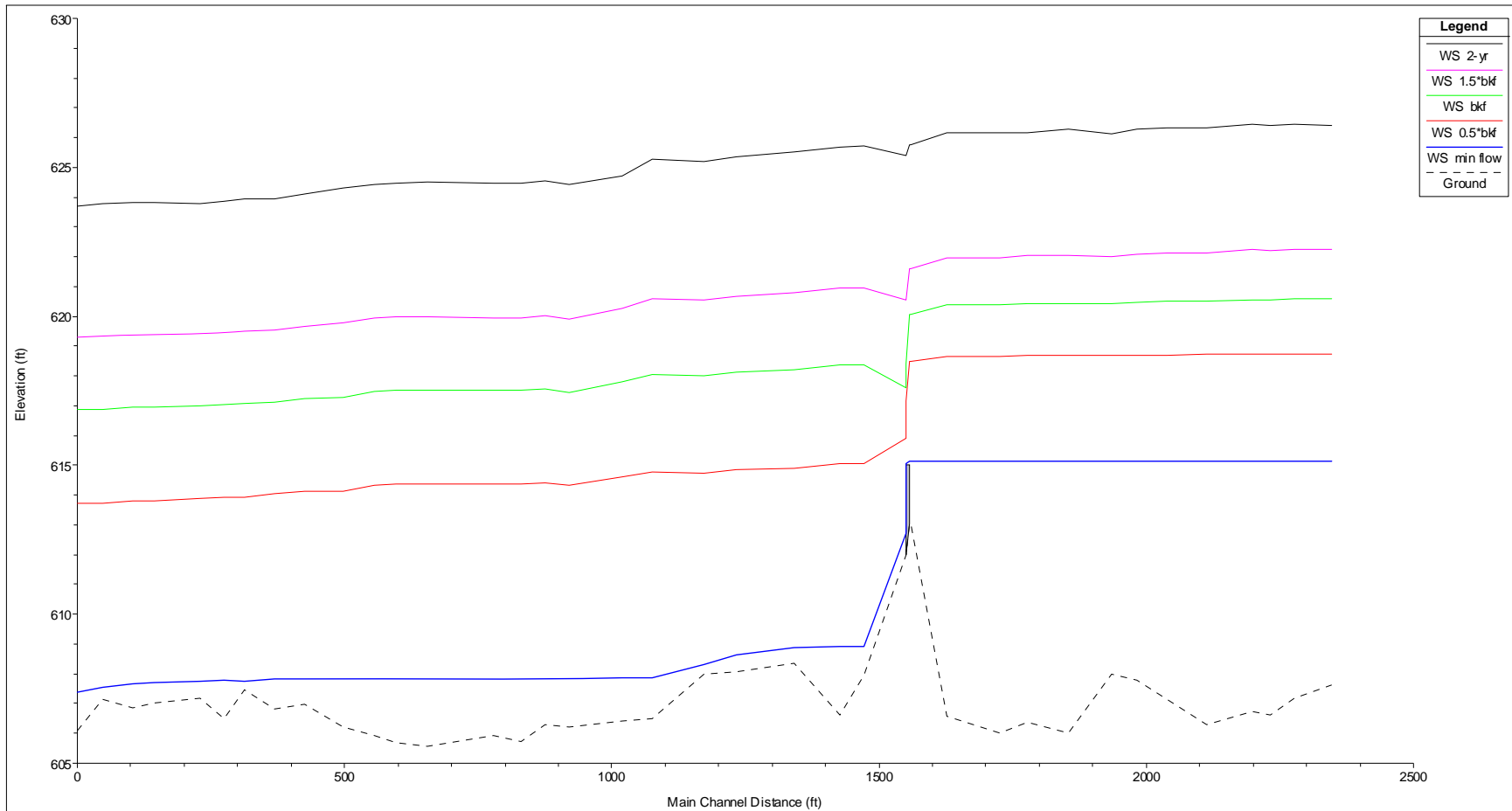


Figure 7. Water surface profiles (solid) and longitudinal profile of the channel bed (dashed) in the project reach for existing conditions. Note the location of the low-head dam by the gray hatch at approximate channel distance 1,500 ft. The effects of the low-head dam on water surfaces for flood flows are less pronounced than for bankfull discharge.

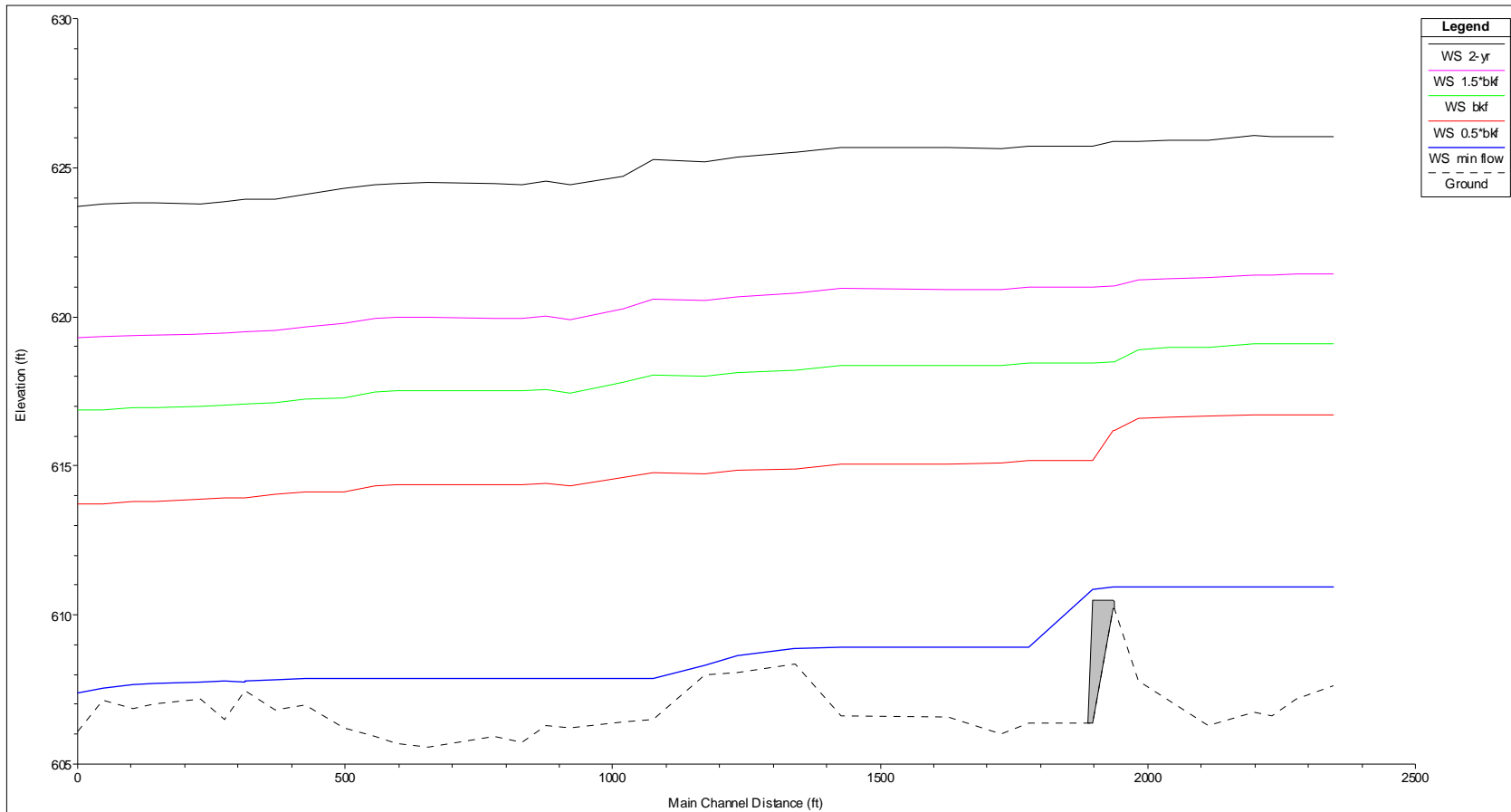


Figure 8. Water surface profiles (solid) and longitudinal profile of the channel bed (dashed) in the project reach for the Preliminary Design conditions. Note the location of the proposed double-invert cross vane by the gray hatch at approximate channel distance 1,900 ft and its influence on low-flow to flood flows. Similar to existing conditions the effects of the vane on water surfaces for flood flows are less pronounced than for bankfull discharge (green); however, the proposed conditions are shown to decrease water levels for flood flows (compare to Fig. 7).