North Platte River Conceptual Design

Town of Saratoga River Study

Prepared for:
Town of Saratoga

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Sign-off Sheet

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1.0 PROJECT BACKGROUND

This report presents a conceptual restoration design for approximately 10,750 ft of the North Platte River through the town of Saratoga, Wyoming (**Figure 1**), and was completed to achieve the objectives of the town and project stakeholders. The conceptual design detailed here is based on the results of a geomorphic assessment conducted by the design team and summarized in the report *Geomorphology and River Assessment* submitted on July 2nd, 2014.

The geomorphic assessment evaluated the nature, extent, and consequences of river impairment and the loss of physical and ecological functions within the evaluation reach of the North Platte River through Saratoga. The existing conditions were compared to reference conditions to determine the degree of impairment and the departure from the potential, geomorphic stable state of the river. The results of the assessment indicated that the North Platte River through Saratoga has a high sediment supply from streambank erosion and is unable to transport the sediment load and the larger particle sizes of sediment generated from the watershed. Also, the aquatic habitat is not operating at its biological potential due to poor instream and overhead cover and poor low flow and high flow refugia.

The conceptual design proposes to increase the sediment transport capacity, competence, and flow hydraulics by reshaping the channel to reduce the extremely high width/depth ratio values. Also, installing instream structures and reestablishing a cottonwood and willow riparian community will reduce the accelerated streambank erosion and will provide long-term stability and ecological function.

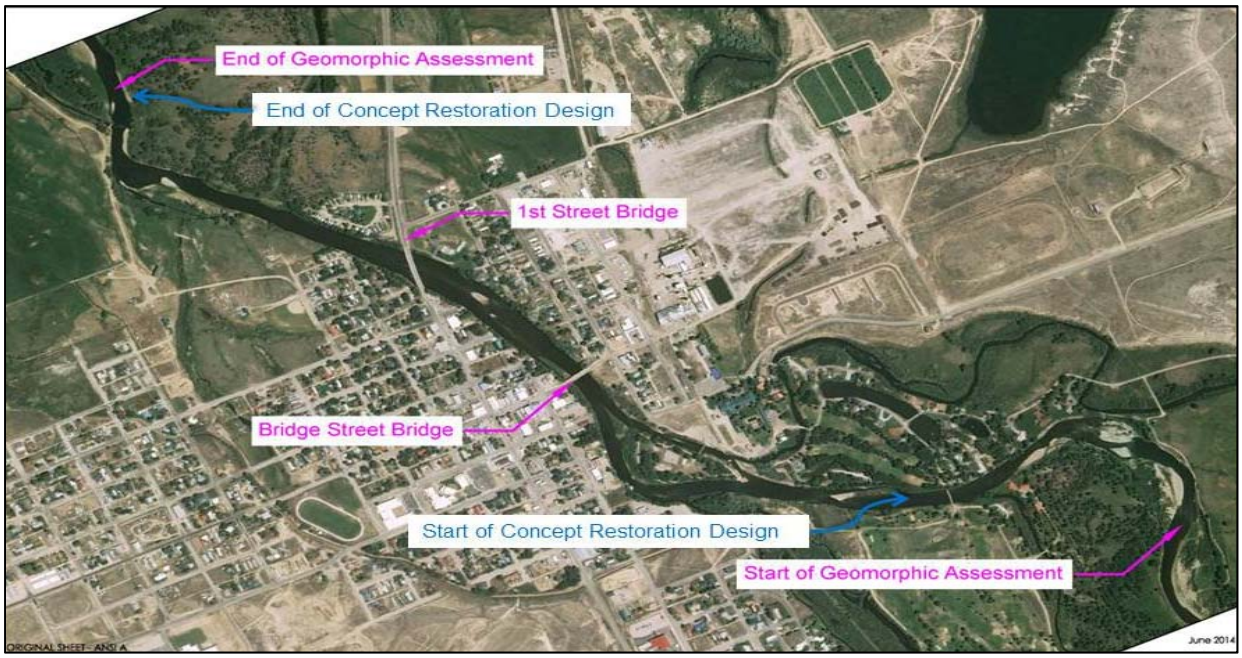

Figure 1. Vicinity map of the reaches associated with the geomorphic assessment and the concept restoration design of the North Platte River through Saratoga.

2.0 PROJECT OBJECTIVES

An integral part of the conceptual design is to determine if the restoration can meet the specific project objectives as formulated by city officials, residents, and local agencies of Saratoga. The conceptual design is directed by the following project objectives:

Objective #1: Design a self-sustaining, natural, stable river

Objective #2: Reduce the flood stage through Saratoga

Objective #3: Reduce the sediment deposition through the reach

Objective #4: Reduce the sediment supply within the project reach

Objective #5: Protect private property and public Infrastructure from erosional processes

Objective #6: Maintain the integrity and function of bridges

Objective #7: Protect river corridor utilities

Objective#8: Protect the hot springs

Objective #9: Improve aquatic habitat

Objective #10: Facilitate recreational boating

Objective #11: Enhance the riparian corridor

Objective #12: Improve the Pick Ditch diversion

3.0 PROJECT CONSTRAINTS

Vertical constraints related to linear infrastructure and pipelines are depicted in **Figure 2** as supplied by the town of Saratoga and detailed in the geomorphic assessment report. Additionally, the presence of bedrock is also a vertical constraint. Due to potential adverse impacts to the hot springs, lowering of the grade at bedrock outcropping locations through excavation will not be considered as a feasible alternative for this project.

The horizontal constraints are primarily defined by the existing top of the river bank and the bridge structures. Because the river is over-wide, a narrow channel can be placed within the existing floodplain to limit the disturbance and loss of private lands. However, a 90 ft corridor along the western shoreline of Veteran's Island will need to be regraded and revegetated; the historic structure at this location may need to be relocated if possible. Also, the proposed pedestrian bridge at 45+22 will have to be reconfigured in a final restoration design.

A - 12" SEWER LINE

B - 12" WATER LINE (SEE EXHIBIT B)

C - 6" PHONE CONDUIT (SEE EXHIBIT C)

D - 12" WATER LINE

E - PEDESTRIAN BRIDGE

F - 10" SEWER LINE

G - 6" WATER LINE (EXPOSED ON SOUTH SIDE)

H - 4" CASING W/ 1 1/4" GAS LINE (SEE EXHIBIT H)

Figure 2. Locations of utilities and encroachment constraints along the North Platte River (map supplied from the town of Saratoga).

4.0 RIVER RESTORATION CONCEPT DESIGN

The conceptual restoration design for the North Platte River through Saratoga uses the Natural Channel Design (NCD) approach developed by Wildland Hydrology (Rosgen, 2007, 2011). NCD is a geomorphic approach to river restoration that relies on analytical, empirical, and analog relationships.

The morphological variables representing the dimensions, pattern, and profile for the conceptual design are developed from naturally stable stream systems identified as reference reaches. A reference reach must be self-maintaining, represent the same potential stream type as the impaired reach, and must occur within a similar valley system that has similar riparian vegetation and flow and sediment regimes.

Reference reach data from the East Fork of the Arkansas River in Colorado, a cobble-bed, C3 stream type (Rosgen, 1994, 1996), was used to develop the values for the conceptual design. Although glacial terraces bound the valley of the East Fork of the Arkansas River, the reach is also bounded by Holocene alluvial terraces and a floodplain. However, the Arkansas River is much smaller than the North Platte (375 cfs); thus pattern and riffle dimension data from a USGS streamgage of the North Platte River at Northgate in Colorado near the Wyoming border was also used to supplement the Arkansas River data.

Detailed methods to determine the dimensions, pattern, and profile for the proposed reach are provided in Rosgen (2007, 2011). The reference reach data is scaled to extrapolate the data to rivers of different sizes by using normalization parameters of bankfull width, mean depth, cross-sectional area, and slope to create dimensionless values. First, the cross-sectional area is determined for the proposed design reach based on the bankfull discharge and an estimated bankfull mean velocity. Then, the bankfull width and mean depth are determined using natural channel design methods. The remaining morphology values are then derived from the dimensionless values of the reference reach by multiplying the reference reach ratio by the corresponding normalization parameter of the proposed reach. For example, all pattern data is normalized by bankfull width; to determine the radius of curvature for the proposed design reach, the dimensionless ratio of radius of curvature to bankfull width of the reference reach is multiplied by the bankfull width of the proposed design reach.

A summary of the proposed morphology data (range and average values) is provided in **Table 1**. The proposed dimensions, pattern, and profile are based on the bankfull discharge of 5,200 cfs and a low flow (inner berm) of 1,100 cfs. The master design table also includes the reference reach data from the Arkansas River and North Platte River at Northgate in addition to the existing reach conditions of the North Platte River to compare to the proposed design.

Table 1. Morphological data comparing the existing, reference, and proposed design reaches (1/6).

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach: EF Arkansas R.	Reference Reach: N. Platte at Northgate
	1	Valley Type	C-GL-GT, U-AL-FD	C-GL-GT, U-AL-FD	C-GL-GT, U-AL-FD	C-GL-GT, U-AL-FD
	2	Valley Width (W_{val})	2400-6300	2400-6300	290-600	1400
	3	Stream Type	C3	C3	C3	C3
	4	Bankfull Discharge, cfs	5200	5200	375	2300
Riffle Dimensions	6	Riffle Width, ft (W_{bkf})	*Mean:* 305.0 *Min:* 272.2 *Max:* 372.7	*Mean:* 170.0 *Min:* 163.0 *Max:* 180.0	*Mean:* 38.8 *Min:* 37.8 *Max:* 39.9	*Mean:* 118.0 *Min:* 98.0 *Max:* 138.0
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* 3.87 *Min:* 3.51 *Max:* 4.27	*Mean:* 5.29 *Min:* 5.48 *Max:* 5.82	*Mean:* 1.70 *Min:* 1.51 *Max:* 1.88	*Mean:* 5.20 *Min:* 4.00 *Max:* 6.20
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* 79.6 *Min:* 63.7 *Max:* 106.2	*Mean:* 31.0 *Min:* 28.0 *Max:* 34.0	*Mean:* 23 *Min:* 21.2 *Max:* 25.1	*Mean:* 25 *Min:* 14 *Max:* 34
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* 1173.7 *Min:* 1075.3 *Max:* 1306.8	*Mean:* 949.0 *Min:* 932.0 *Max:* 953.0	*Mean:* 66.0 *Min:* 57.1 *Max:* 75.0	*Mean:* 566.0 *Min:* 57.0 *Max:* 75.0
	10	Riffle Maximum Depth (d_{max})	*Mean:* 6.47 *Min:* 4.95 *Max:* 7.15	*Mean:* 8.22 *Min:* 8.21 *Max:* 9.02	*Mean:* 2.79 *Min:* 2.65 *Max:* 2.95	*Mean:* 2.79 *Min:* 2.65 *Max:* 2.95
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* 1.681 *Min:* 1.320 *Max:* 1.927	*Mean:* 1.55 *Min:* 1.50 *Max:* 1.60	*Mean:* 1.686 *Min:* 1.569 *Max:* 1.834	*Mean:* 1.686 *Min:* 1.569 *Max:* 1.834
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* 1983.5 *Min:* 324.0 *Max:* 6300.0	*Mean:* 1983.5 *Min:* 1000.0 *Max:* 6300.0	*Mean:* 281 *Min:* 220.0 *Max:* 320.0	*Mean:* 1400 *Min:* 220.0 *Max:* 320.0
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* 6.8 *Min:* 1.1 *Max:* 21.7	*Mean:* 6.8 *Min:* 5.9 *Max:* 21.7	*Mean:* 7.3 *Min:* 5.5 *Max:* 8.5	*Mean:* 13 *Min:* 5.5 *Max:* 8.5
Riffle Inner Berm Dimensions	14	Riffle Inner Berm Width, ft (W_{ib})	*Mean:* 173.7 *Min:* 87.2 *Max:* 239.5	*Mean:* 86.0 *Min:* 84.0 *Max:* 88.0	*Mean:* 21.3 *Min:* 18.3 *Max:* 23.3	
	15	Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:* 0.580 *Min:* 0.294 *Max:* 0.860	*Mean:* 0.51 *Min:* 0.49 *Max:* 0.52	*Mean:* 0.552 *Min:* 0.485 *Max:* 0.586	
	16	Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:* 1.35 *Min:* 0.86 *Max:* 1.69	*Mean:* 3.30 *Min:* 3.17 *Max:* 3.39	*Mean:* 0.66 *Min:* 0.51 *Max:* 0.79	
	17	Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:* 0.352 *Min:* 0.238 *Max:* 0.480	*Mean:* 0.624 *Min:* 0.599 *Max:* 0.641	*Mean:* 0.394 *Min:* 0.320 *Max:* 0.444	
	18	Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:* 131.2 *Min:* 72.2 *Max:* 201.0	*Mean:* 25.3 *Min:* 25.4 *Max:* 27.8	*Mean:* 33.6 *Min:* 27.4 *Max:* 43.6	
	19	Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:* 237.8 *Min:* 75.4 *Max:* 366.1	*Mean:* 284.0 *Min:* 279.0 *Max:* 285.0	*Mean:* 14.0 *Min:* 11.4 *Max:* 18.4	
	20	Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:* 0.201 *Min:* 0.070 *Max:* 0.282	*Mean:* 0.30 *Min:* 0.29 *Max:* 0.30	*Mean:* 0.216 *Min:* 0.187 *Max:* 0.245	

Table 1. Morphological data comparing the existing, reference, and proposed design reaches (2/6).

	Entry Number & Variable		Existing Reach		Proposed Design Reach		Reference Reach: EF Arkansas R.	
Pool Dimensions	21	Pool Width, ft (W_{bkfp})	*Mean:*	**245.9**	*Mean:*	**170.0**	*Mean:*	**35.8**
			Min:	**186.3**	*Min:*	**163.0**	*Min:*	**31.5**
			Max:	**417.5**	*Max:*	**180.0**	*Max:*	**40.0**
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:*	**0.816**	*Mean:*	**1.0**	*Mean:*	**0.897**
			Min:	**0.618**	*Min:*	**1.0**	*Min:*	**0.790**
			Max:	**1.385**	*Max:*	**1.0**	*Max:*	**1.004**
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:*	**4.82**	*Mean:*	**6.2**	*Mean:*	**2.32**
			Min:	**3.86**	*Min:*	**5.7**	*Min:*	**2.27**
			Max:	**5.86**	*Max:*	**6.8**	*Max:*	**2.37**
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:*	**1.303**	*Mean:*	**1.17**	*Mean:*	**1.234**
			Min:	**1.043**	*Min:*	**1.07**	*Min:*	**1.207**
			Max:	**1.584**	*Max:*	**1.28**	*Max:*	**1.261**
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:*	**51.0**	*Mean:*	**27.4**	*Mean:*	**15.4**
			Min:	**31.8**	*Min:*	**31.7**	*Min:*	**13.3**
			Max:	**108.2**	*Max:*	**24.0**	*Max:*	**17.6**
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:*	**1146.1**	*Mean:*	**1056.0**	*Mean:*	**83.2**
			Min:	**846.3**	*Min:*	**1023.0**	*Min:*	**71.6**
			Max:	**1612.2**	*Max:*	**1106.0**	*Max:*	**94.7**
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:*	**1.039**	*Mean:*	**1.11**	*Mean:*	**1.107**
			Min:	**0.767**	*Min:*	**1.08**	*Min:*	**0.954**
			Max:	**1.461**	*Max:*	**1.17**	*Max:*	**1.261**
	28	Pool Maximum Depth (d_{maxp})	*Mean:*	**7.57**	*Mean:*	**13.3**	*Mean:*	**4.90**
			Min:	**5.53**	*Min:*	**12.7**	*Min:*	**4.52**
			Max:	**8.68**	*Max:*	**14.0**	*Max:*	**5.27**
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:*	**2.046**	*Mean:*	**2.5**	*Mean:*	**2.606**
			Min:	**1.495**	*Min:*	**2.4**	*Min:*	**2.404**
			Max:	**2.346**	*Max:*	**2.6**	*Max:*	**2.803**
	30	Point Bar Slope (S_{pb})	*Mean:*	**0.008**	*Mean:*	**0.091**	*Mean:*	**33.300**
			Min:	**0.040**	*Min:*	**0.080**	*Min:*	**28.600**
			Max:	**0.110**	*Max:*	**0.110**	*Max:*	**38.000**
Pool Inner Berm Dimensions	31	Pool Inner Berm Width, ft (W_{ibp})	*Mean:*	**181.8**	*Mean:*	**115.0**	*Mean:*	**16.9**
			Min:	**135.3**	*Min:*	**110.0**	*Min:*	**15.1**
			Max:	**249.4**	*Max:*	**125.0**	*Max:*	**18.8**
	32	Pool Inner Berm Width to Pool Width (W_{ibp}/W_{bkfp})	*Mean:*	**0.752**	*Mean:*	**0.68**	*Mean:*	**0.475**
			Min:	**0.546**	*Min:*	**0.65**	*Min:*	**0.470**
			Max:	**0.931**	*Max:*	**0.74**	*Max:*	**0.480**
	33	Pool Inner Berm Mean Depth, ft (d_{ibp})	*Mean:*	**2.51**	*Mean:*	**3.48**	*Mean:*	**1.89**
			Min:	**1.50**	*Min:*	**2.80**	*Min:*	**1.68**
			Max:	**4.00**	*Max:*	**4.09**	*Max:*	**2.09**
	34	Pool Inner Berm Mean Depth to Pool Mean Depth (d_{ibp}/d_{bkfp})	*Mean:*	**0.528**	*Mean:*	**0.56**	*Mean:*	**0.815**
			Min:	**0.299**	*Min:*	**0.45**	*Min:*	**0.709**
			Max:	**0.881**	*Max:*	**0.66**	*Max:*	**0.921**
	35	Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})	*Mean:*	**87.4**	*Mean:*	**33.1**	*Mean:*	**9.2**
			Min:	**33.9**	*Min:*	**44.6**	*Min:*	**7.2**
			Max:	**166.3**	*Max:*	**26.9**	*Max:*	**11.2**
	36	Pool Inner Berm Cross-Sectional Area (A_{ibp})	*Mean:*	**427.4**	*Mean:*	**400**	*Mean:*	**31.6**
			Min:	**242.5**	*Min:*	**350**	*Min:*	**31.6**
			Max:	**541.0**	*Max:*	**450**	*Max:*	**31.6**
	37	Pool Inner Berm Cross-Sectional Area to Pool Cross-Sectional Area (A_{ibp}/A_{bkfp})	*Mean:*	**0.387**	*Mean:*	**0.38**	*Mean:*	**0.387**
			Min:	**0.215**	*Min:*	**0.33**	*Min:*	**0.333**
			Max:	**0.639**	*Max:*	**0.43**	*Max:*	**0.441**

Table 1. Morphological data comparing the existing, reference, and proposed design reaches (3/6).

Entry Number & Variable			Existing Reach		Proposed Design Reach		Reference Reach: EF Arkansas R.	
Run Dimensions	38	Run Width, ft (W_{bkfr})	*Mean:*	**286.6**	*Mean:*	**172.6**	*Mean:*	**40.5**
			Min:	**225.6**	*Min:*	**163.0**	*Min:*	
			Max:	**347.6**	*Max:*	**189.0**	*Max:*	
	39	Run Width to Riffle Width (W_{bkfr}/W_{bkf})	*Mean:*	**0.951**	*Mean:*	**1.02**	*Mean:*	**1.015**
			Min:	**0.748**	*Min:*	**1.00**	*Min:*	
			Max:	**1.153**	*Max:*	**1.05**	*Max:*	
	40	Run Mean Depth, ft (d_{bkfr})	*Mean:*	**4.06**	*Mean:*	**5.39**	*Mean:*	**1.82**
			Min:	**3.24**	*Min:*	**4.68**	*Min:*	
			Max:	**4.87**	*Max:*	**5.85**	*Max:*	
	41	Run Mean Depth to Riffle Mean Depth (d_{bkfr}/d_{bkf})	*Mean:*	**1.097**	*Mean:*	**1.02**	*Mean:*	**0.968**
			Min:	**0.876**	*Min:*	**0.89**	*Min:*	
			Max:	**1.316**	*Max:*	**1.11**	*Max:*	
	42	Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})	*Mean:*	**76.8**	*Mean:*	**32.0**	*Mean:*	**22.2**
			Min:	**46.3**	*Min:*	**27.9**	*Min:*	
			Max:	**107.3**	*Max:*	**40.3**	*Max:*	
	43	Run Cross-Sectional Area, ft^2 (A_{bkfr})	*Mean:*	**1112.6**	*Mean:*	**930.0**	*Mean:*	**73.8**
			Min:	**1099.4**	*Min:*	**885.4**	*Min:*	
			Max:	**1125.8**	*Max:*	**953.0**	*Max:*	
	44	Run Area to Riffle Area (A_{bkfr}/A_{bkf})	*Mean:*	**1.008**	*Mean:*	**0.980**	*Mean:*	**0.982**
			Min:	**0.996**	*Min:*	**0.950**	*Min:*	
			Max:	**1.020**	*Max:*	**1.000**	*Max:*	
	45	Run Maximum Depth (d_{maxr})	*Mean:*	**6.7**	*Mean:*	**9.5**	*Mean:*	**3.39**
			Min:	**5.7**	*Min:*	**9.3**	*Min:*	
			Max:	**7.8**	*Max:*	**9.7**	*Max:*	
	46	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:*	**1.819**	*Mean:*	**1.80**	*Mean:*	**1.803**
			Min:	**1.532**	*Min:*	**1.76**	*Min:*	
			Max:	**2.103**	*Max:*	**1.83**	*Max:*	

Table 1. Morphological data comparing the existing, reference, and proposed design reaches (4/6).

Entry Number & Variable			Existing Reach		Proposed Design Reach		Reference Reach: EF Arkansas R.	
Glide Dimensions	47	Glide Width, ft (W_{bkfg})	*Mean:*	**347.8**	*Mean:*	**181.9**	*Mean:*	**42.7**
			Min:	**309.5**	*Min:*	**167.6**	*Min:*	**39.3**
			Max:	**386.1**	*Max:*	**196.2**	*Max:*	**46.0**
	48	Glide Width to Riffle Width (W_{bkfg}/W_{bkf})	*Mean:*	**1.154**	*Mean:*	**1.070**	*Mean:*	**1.070**
			Min:	**1.027**	*Min:*	**0.986**	*Min:*	**0.986**
			Max:	**1.281**	*Max:*	**1.154**	*Max:*	**1.154**
	49	Glide Mean Depth, ft (d_{bkfg})	*Mean:*	**3.32**	*Mean:*	**5.02**	*Mean:*	**1.68**
			Min:	**2.79**	*Min:*	**3.84**	*Min:*	**1.52**
			Max:	**3.84**	*Max:*	**6.39**	*Max:*	**1.84**
	50	Glide Mean Depth to Riffle Mean Depth (d_{bkfg}/d_{bkf})	*Mean:*	**0.897**	*Mean:*	**0.948**	*Mean:*	**0.894**
			Min:	**0.754**	*Min:*	**0.726**	*Min:*	**0.809**
			Max:	**1.038**	*Max:*	**1.209**	*Max:*	**0.979**
	51	Glide Width/Depth Ratio (W_{bkfg}/d_{bkfg})	*Mean:*	**109.5**	*Mean:*	**36.3**	*Mean:*	**25.4**
			Min:	**80.6**	*Min:*	**26.2**	*Min:*	**25.0**
			Max:	**138.4**	*Max:*	**51.1**	*Max:*	**25.9**
	52	Glide Cross-Sectional Area, ft^2 (A_{bkfg})	*Mean:*	**1132.4**	*Mean:*	**912.2**	*Mean:*	**72.2**
			Min:	**1077.5**	*Min:*	**753.1**	*Min:*	**59.6**
			Max:	**1187.3**	*Max:*	**1071.3**	*Max:*	**84.8**
	53	Glide Area to Riffle Area (A_{bkfg}/A_{bkf})	*Mean:*	**1.026**	*Mean:*	**0.96**	*Mean:*	**0.961**
			Min:	**0.977**	*Min:*	**0.79**	*Min:*	**0.794**
			Max:	**1.076**	*Max:*	**1.13**	*Max:*	**1.129**
	54	Glide Maximum Depth (d_{maxg})	*Mean:*	**5.69**	*Mean:*	**6.39**	*Mean:*	**2.27**
			Min:	**5.39**	*Min:*	**6.02**	*Min:*	**2.14**
			Max:	**5.98**	*Max:*	**6.75**	*Max:*	**2.40**
	55	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:*	**1.538**	*Mean:*	**1.207**	*Mean:*	**1.207**
			Min:	**1.457**	*Min:*	**1.138**	*Min:*	**1.138**
			Max:	**1.616**	*Max:*	**1.277**	*Max:*	**1.277**
Glide Inner Berm Dimensions	56	Glide Inner Berm Width, ft (W_{ibg})	*Mean:*	**240.6**	*Mean:*	**104.6**	*Mean:*	**24.7**
			Min:	**202.7**	*Min:*	**96.0**	*Min:*	**20.8**
			Max:	**278.6**	*Max:*	**113.1**	*Max:*	**28.6**
	57	Glide Inner Berm Width to Glide Width (W_{ibg}/W_{bkfg})	*Mean:*	**0.713**	*Mean:*	**0.575**	*Mean:*	**0.575**
			Min:	**0.525**	*Min:*	**0.528**	*Min:*	**0.528**
			Max:	**0.900**	*Max:*	**0.622**	*Max:*	**0.622**
	58	Glide Inner Berm Mean Depth, ft (d_{ibg})	*Mean:*	**0.92**	*Mean:*	**1.33**	*Mean:*	**0.43**
			Min:	**0.88**	*Min:*	**0.93**	*Min:*	**0.34**
			Max:	**0.96**	*Max:*	**1.73**	*Max:*	**0.52**
	59	Glide Inner Berm Mean Depth to Glide Mean Depth (d_{ibg}/d_{bkfg})	*Mean:*	**0.283**	*Mean:*	**0.265**	*Mean:*	**0.265**
			Min:	**0.251**	*Min:*	**0.185**	*Min:*	**0.185**
			Max:	**0.315**	*Max:*	**0.345**	*Max:*	**0.345**
	60	Glide Inner Berm Width/Depth Ratio (W_{ibg}/d_{ibg})	*Mean:*	**259.7**	*Mean:*	**61.9**	*Mean:*	**61.9**
			Min:	**230.4**	*Min:*	**39.6**	*Min:*	**39.6**
			Max:	**289.0**	*Max:*	**84.2**	*Max:*	**84.2**
	61	Glide Inner Berm Cross-Sectional Area (A_{ibg})	*Mean:*	**223.4**	*Mean:*	**135.9**	*Mean:*	**10.3**
			Min:	**178.3**	*Min:*	**104.9**	*Min:*	**9.7**
			Max:	**268.6**	*Max:*	**166.9**	*Max:*	**10.9**
	62	Glide Inner Berm Area to Glide Area (A_{ibg}/A_{bkfg})	*Mean:*	**0.196**	*Mean:*	**0.149**	*Mean:*	**0.149**
			Min:	**0.165**	*Min:*	**0.115**	*Min:*	**0.115**
			Max:	**0.226**	*Max:*	**0.183**	*Max:*	**0.183**

Table 1. Morphological data comparing the existing, reference, and proposed design reaches (5/6).

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach: EF Arkansas R.	Reference Reach: N. Platte at Northgate
Channel Pattern	63	Linear Wavelength, ft (λ)	*Mean:* **3359.0** *Min:* **1752.0** *Max:* **4746.0**	*Mean:* **2200** *Min:* **1600** *Max:* **2500**	*Mean:* **304** *Min:* **240** *Max:* **328**	*Mean:* **1720** *Min:* **1560** *Max:* **1900**
	67	Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:* **11.146** *Min:* **5.813** *Max:* **15.748**	*Mean:* **12.9** *Min:* **9.4** *Max:* **14.7**	*Mean:* **7.6** *Min:* **6** *Max:* **8.2**	*Mean:* **12.5** *Min:* **11.3** *Max:* **13.8**
	65	Stream Meander Length, ft (L_m)	*Mean:* **3966.0** *Min:* **2353.0** *Max:* **5016.0**	*Mean:* **2400** *Min:* **1750** *Max:* **2650**	*Mean:* **456** *Min:* **359** *Max:* **560**	*Mean:* **2270** *Min:* **2000** *Max:* **2600**
	66	Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:* **13.160** *Min:* **7.808** *Max:* **16.644**	*Mean:* **14.1** *Min:* **10.3** *Max:* **15.6**	*Mean:* **11.4** *Min:* **9** *Max:* **14**	*Mean:* **16.4** *Min:* **14.5** *Max:* **18.8**
	67	Belt Width, ft (W_{blt})	*Mean:* **1256.0** *Min:* **905.0** *Max:* **1606.0**	*Mean:* **225** *Min:* **350** *Max:* **650**	*Mean:* **172** *Min:* **80** *Max:* **348**	*Mean:* **759** *Min:* **414** *Max:* **1104**
	68	Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:* **4.168** *Min:* **3.003** *Max:* **5.329**	*Mean:* **1.3** *Min:* **2.1** *Max:* **3.8**	*Mean:* **4.3** *Min:* **2** *Max:* **8.7**	*Mean:* **5.5** *Min:* **3.0** *Max:* **8.0**
	69	Radius of Curvature, ft (R_c)	*Mean:* **818.0** *Min:* **202.0** *Max:* **2429.0**	*Mean:* **525** *Min:* **370** *Max:* **740**	*Mean:* **136** *Min:* **92** *Max:* **180**	*Mean:* **607** *Min:* **455** *Max:* **718**
	70	Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:* **2.714** *Min:* **0.670** *Max:* **8.060**	*Mean:* **3.1** *Min:* **2.2** *Max:* **4.4**	*Mean:* **3.4** *Min:* **2.3** *Max:* **4.5**	*Mean:* **4.4** *Min:* **3.3** *Max:* **5.2**
	71	Arc Length, ft (L_a)	*Mean:* **567.0** *Min:* **347.0** *Max:* **973.0**	*Mean:* **550.0** *Min:* **340.0** *Max:* **675.0**	*Mean:* **144** *Min:* **80** *Max:* **220**	*Mean:* **828** *Min:* **552** *Max:* **1104**
	72	Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:* **1.881** *Min:* **1.151** *Max:* **3.229**	*Mean:* **3.2** *Min:* **2.0** *Max:* **4.0**	*Mean:* **3.6** *Min:* **2** *Max:* **5.5**	*Mean:* **6.0** *Min:* **4.0** *Max:* **8.0**
	73	Riffle Length (L_r), ft	*Mean:* **407.1** *Min:* **147.0** *Max:* **1034.3**	*Mean:* **425.0** *Min:* **340.0** *Max:* **615.0**	*Mean:* **78.56** *Min:* **67.28** *Max:* **100.33**	*Mean:* **78.56** *Min:* **67.28** *Max:* **100.33**
	74	Riffle Length to Riffle Width (L_r/W_{bkf})	*Mean:* **1.351** *Min:* **0.488** *Max:* **3.432**	*Mean:* **2.5** *Min:* **2.0** *Max:* **3.6**	*Mean:* **1.97** *Min:* **1.69** *Max:* **2.52**	*Mean:* **1.97** *Min:* **1.69** *Max:* **2.52**
	75	Individual Pool Length, ft (L_p)	*Mean:* **1573.5** *Min:* **983.0** *Max:* **2633.4**	*Mean:* **300.0** *Min:* **220.0** *Max:* **610.0**	*Mean:* **62.8** *Min:* **53.4** *Max:* **74.9**	*Mean:* **62.8** *Min:* **53.4** *Max:* **74.9**
	76	Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:* **5.221** *Min:* **3.262** *Max:* **8.738**	*Mean:* **1.8** *Min:* **1.3** *Max:* **3.6**	*Mean:* **1.58** *Min:* **1.34** *Max:* **1.88**	*Mean:* **1.58** *Min:* **1.34** *Max:* **1.88**
	77	Pool-to-Pool Spacing, ft (P_s)	*Mean:* **1983.0** *Min:* **1176.0** *Max:* **2508.0**	*Mean:* **950.0** *Min:* **550.0** *Max:* **1360.0**	*Mean:* **161** *Min:* **160** *Max:* **162**	*Mean:* **1135** *Min:* **1000** *Max:* **1300**
	78	Pool-to-Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:* **6.600** *Min:* **4.000** *Max:* **8.300**	*Mean:* **5.6** *Min:* **3.2** *Max:* **8.0**	*Mean:* **4.1** *Min:* **4** *Max:* **4.1**	*Mean:* **8.2** *Min:* **7.2** *Max:* **9.4**
Sinuosity and Slope	79	Stream Length (SL)	**10767.0**	**7876.8**	**600**	**5400**
	80	Valley Length (VL)	**9203.0**	**7120.0**	**400**	**4500**
	81	Valley Slope (S_{val})	**0.0026**	**0.0026**	**0.015**	**0.00417**
	82	Sinuosity (k)	SL/VL: **1.17**	SL/VL: **1.11**	SL/VL: **1.50** VS/S: **1.50**	SL/VL: **1.20** VS/S: **1.20**
	83	Average Water Surface Slope (S)	**0.0022**	**0.0025**	**0.0100**	**0.0050**

Table 1. Morphological data comparing the existing, reference, and proposed design reaches (6/6).

Entry Number & Variable			Existing Reach		Proposed Design Reach		Reference Reach: EF Arkansas R.	
Profile Bed Feature Max Depth Measurements	87	Riffle Maximum Depth, ft (d_{max})	*Mean:*	**4.51**	*Mean:*	**0.0043**	*Mean:*	**3.26**
			Min:	**3.85**	*Min:*	**0.0040**	*Min:*	**3.04**
			Max:	**5.20**	*Max:*	**0.0045**	*Max:*	**3.39**
	88	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:*	**1.219**	*Mean:*	**1.7**	*Mean:*	**1.734**
			Min:	**1.041**	*Min:*	**1.6**	*Min:*	**1.617**
			Max:	**1.405**	*Max:*	**1.8**	*Max:*	**1.803**
	89	Pool Maximum Depth, ft (d_{maxp})	*Mean:*	**8.64**	*Mean:*	**0.0065**	*Mean:*	**4.90**
			Min:	**7.25**	*Min:*	**0.0058**	*Min:*	**4.24**
			Max:	**9.46**	*Max:*	**0.0070**	*Max:*	**5.25**
	90	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:*	**2.335**	*Mean:*	**2.6**	*Mean:*	**2.606**
			Min:	**1.959**	*Min:*	**2.3**	*Min:*	**2.255**
			Max:	**2.557**	*Max:*	**2.8**	*Max:*	**2.793**
	91	Run Maximum Depth, ft (d_{maxr})	*Mean:*	**5.06**	*Mean:*	**0.0045**	*Mean:*	**3.43**
			Min:	**3.90**	*Min:*	**0.0043**	*Min:*	**3.16**
			Max:	**5.85**	*Max:*	**0.0050**	*Max:*	**3.69**
	92	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:*	**1.368**	*Mean:*	**1.8**	*Mean:*	**1.824**
			Min:	**1.054**	*Min:*	**1.7**	*Min:*	**1.681**
			Max:	**1.581**	*Max:*	**2.0**	*Max:*	**1.963**
	93	Glide Maximum Depth, ft (d_{maxg})	*Mean:*	**3.09**	*Mean:*	**0.0033**	*Mean:*	**2.46**
			Min:	**2.15**	*Min:*	**0.0028**	*Min:*	**2.16**
			Max:	**4.80**	*Max:*	**0.0038**	*Max:*	**2.77**
	94	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:*	**0.835**	*Mean:*	**1.3**	*Mean:*	**1.309**
			Min:	**0.581**	*Min:*	**1.1**	*Min:*	**1.149**
			Max:	**1.297**	*Max:*	**1.5**	*Max:*	**1.473**
Profile Bed / Water Surface Slopes	97	Riffle Slope (water surface facet slope) (S_{rif})	*Mean:*	**0.0040**	*Mean:*	**0.0040**	*Mean:*	**0.0163**
			Min:	**0.0010**	*Min:*	**0.0033**	*Min:*	**0.0133**
			Max:	**0.0050**	*Max:*	**0.0054**	*Max:*	**0.0211**
	98	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:*	**1.8349**	*Mean:*	**1.6**	*Mean:*	**1.6260**
			Min:	**0.4587**	*Min:*	**1.3**	*Min:*	**1.3280**
			Max:	**2.2936**	*Max:*	**2.2**	*Max:*	**2.1140**
	99	Pool Slope (water surface facet slope) (S_p)	*Mean:*	**0.0006**	*Mean:*	**0.0004**	*Mean:*	**0.0010**
			Min:	**0.0002**	*Min:*	**0.0002**	*Min:*	**0.0010**
			Max:	**0.0010**	*Max:*	**0.0005**	*Max:*	**0.0022**
	100	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:*	**0.2752**	*Mean:*	**0.15**	*Mean:*	**0.1500**
			Min:	**0.0826**	*Min:*	**0.10**	*Min:*	**0.1000**
			Max:	**0.4771**	*Max:*	**0.22**	*Max:*	**0.2150**
	101	Run Slope (water surface facet slope) (S_{run})	*Mean:*	**0.0160**	*Mean:*	**0.0047**	*Mean:*	**0.0192**
			Min:	**0.0040**	*Min:*	**0.0029**	*Min:*	**0.0119**
			Max:	**0.0340**	*Max:*	**0.0065**	*Max:*	**0.0264**
	102	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:*	**7.3394**	*Mean:*	**1.9**	*Mean:*	**1.9230**
			Min:	**1.8349**	*Min:*	**1.2**	*Min:*	**1.1870**
			Max:	**15.5963**	*Max:*	**2.6**	*Max:*	**2.6420**
	103	Glide Slope (water surface facet slope) (S_g)	*Mean:*	**0.0009**	*Mean:*	**0.0003**	*Mean:*	**0.0013**
			Min:	**0.0007**	*Min:*	**0.0002**	*Min:*	**0.0009**
			Max:	**0.0010**	*Max:*	**0.0004**	*Max:*	**0.0017**
	104	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:*	**0.4128**	*Mean:*	**0.132**	*Mean:*	**0.1320**
			Min:	**0.3165**	*Min:*	**0.092**	*Min:*	**0.0920**
			Max:	**0.4771**	*Max:*	**0.171**	*Max:*	**0.1710**

4.1 PROPOSED CHANNEL DIMENSIONS

The dimensions of the existing channel are significantly different from the reference conditions and require a narrowing and deepening of the channel and creating a lower floodplain. The reference reaches have width/depth ratio values that range from 14–34 compared to the 64–106 values of the existing reach. The entrenchment ratios (measure of vertical containment) of the reference reaches were 5.5–8.5 compared to the existing reach that has sections with values as low as 1.1 (indicating vertical containment) due to the high width/depth ratios.

Due to the vertical constraints of buried utility lines and bedrock that control the bed elevations, the design reach was broken into two separate reaches with slightly differing typical designs. To meet the project goals related to flood stage reduction and improved sediment transport to reduce maintenance, the designs convey the lowest width/depth ratio and steepest slope possible.

The upper reach spans 4,600 ft in length from station 31+00 to 77+00. The typical riffle width/depth ratio for this location is 34 with a channel slope of 0.0025. The lower reach spans 2,200 ft in length from station 82+00 to 104+00; the typical width/depth ratio for this location is 28 with a channel slope of 0.0022. The typical riffle designs have the ability to convey 5,200 cfs with the maximum possible reduction in flood stage and hydraulic efficiency without utility replacement. Also, the defined low flow dimensions associated with 1,100 cfs will increase the sediment transport capacity and will improve the conditions for aquatic habitat.

Table 1 summarizes the average and range of dimensions for the proposed bankfull and low flow channels for riffle, run, pool, and glide features. **Table 2** summarizes the typical bankfull and low flow riffle dimensions (all within the range of values in **Table 1**) associated with a designed 34 width/depth ratio on the upper reach and a designed 28 width/depth ratio on the lower reach. Overlays of the proposed *versus* existing dimensions for the upper and lower reach riffles and a typical pool, run, and glide are depicted in **Figure 3**. These overlays reflect the typical dimensions and the extent of excavation required to shape the proposed cross-sections.

Table 2. Typical design dimensions for the bankfull and low flow channels for two typical riffle designs associated with width/depth ratios of 34 and 28.

Location	Dimensions: Bankfull Discharge (5,200 cfs)					Dimensions: Low Flow (1,100 cfs)			
	Width (ft)	Mean Depth (ft)	Max. Depth (ft)	W/D Ratio (ft/ft)	Cross-Sectional Area (ft^2)	Width (ft)	Mean Depth (ft)	W/D Ratio (ft/ft)	Cross-Sectional Area (ft^2)
Riffles									
Upper Reach	180	5.3	8.21	34	953	86.7	3.23	26.8	280
Lower Reach	163	5.8	9.02	28	949	83.6	3.36	25.0	280

Figure 3a. Proposed *versus* existing overlays representing typical dimensions for the upper riffle reach and a run of the North Platte River through Saratoga, Wyoming.

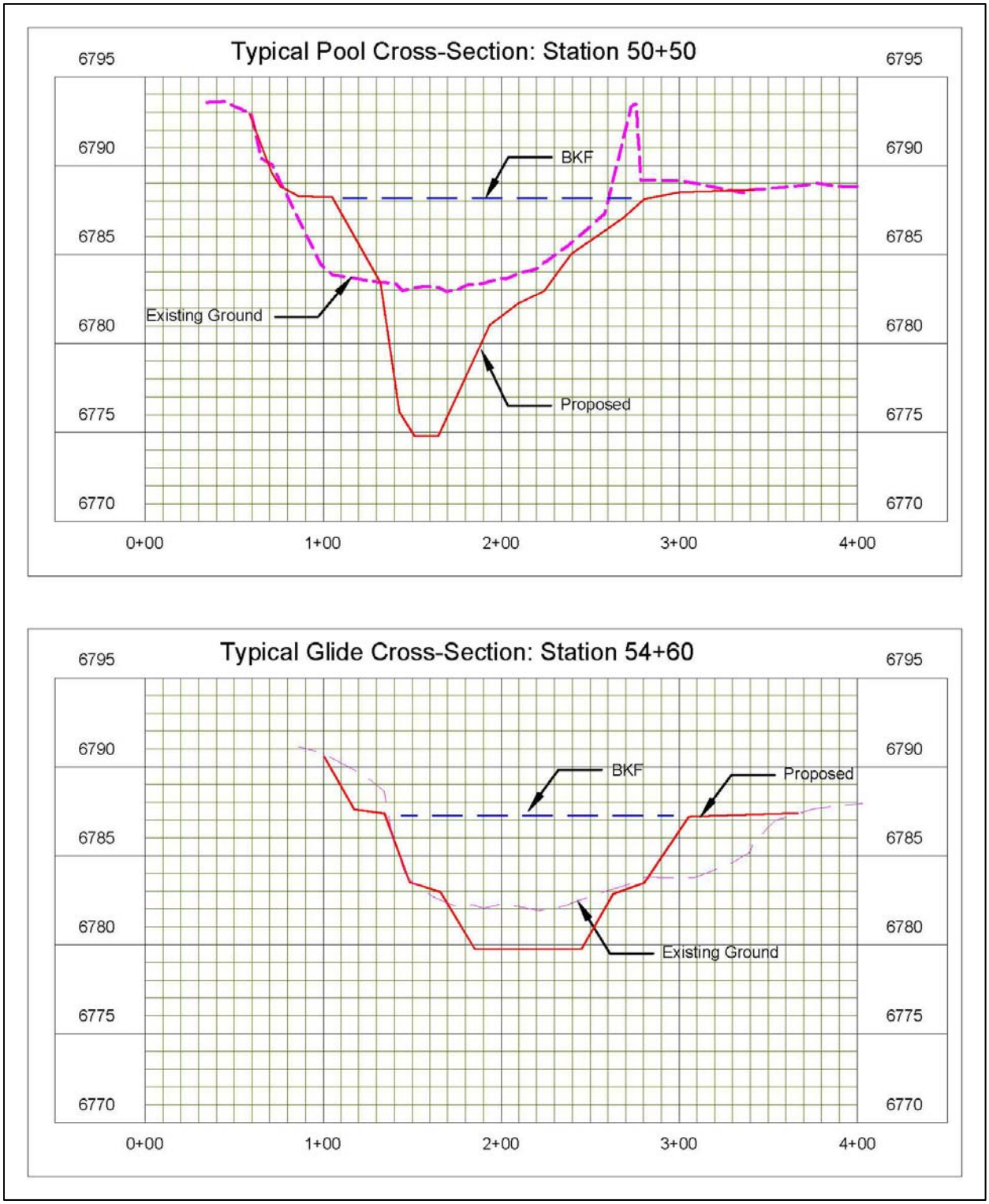

Figure 3b. Proposed *versus* existing overlays representing typical dimensions of a pool and glide of the North Platte River through Saratoga, Wyoming.

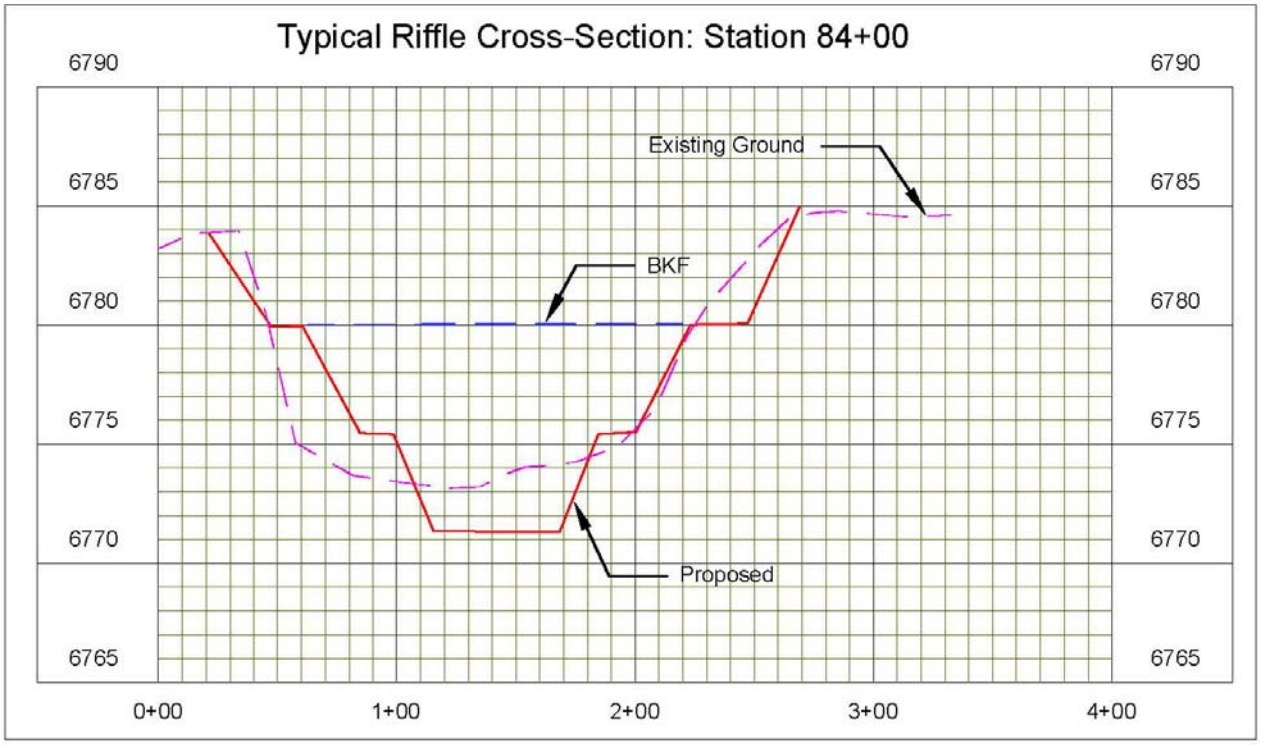

Figure 3c. Proposed *versus* existing overlays representing typical dimensions of the lower reach riffle of the North Platte River through Saratoga, Wyoming.

4.2 PROPOSED CHANNEL PATTERN

The channel pattern is controlled by the lateral constraints within the river corridor. With the exception of the low radius of curvature value at the lower reach, the existing meander pattern values are within the range of values of the reference reaches (**Table 1**).

The plan view of the proposed channel alignment depicts the narrowing of the channel and removal of in-channel bars (**Figure 4**). The proposed sinuosity is 1.11 for the project reach, which is similar to the reference reach value of 1.2 of the North Platte River at Northgate. Also, the existing riffle lengths associated with a ratio of 0.5 widths are too low and are lengthened in the conceptual design.

The proposed alignment utilizes existing banks that have good riparian cover where possible. Much of the narrowing of the main channel width as depicted in **Figure 4** is afforded by creating a floodplain within the inside of river bends as shown between the two river bridges through Saratoga. A large amount of fill is required on the last bend above the irrigation diversion to construct a bankfull bench against an actively eroding terrace bank and to increase the radius of curvature. The small tributary coming in from the west will be relocated and stabilized through the new fill. The conceptual design at this location will reduce the excess deposition and accelerated streambank erosion (**Figure 4**).

The upper reach at the start of Veteran's Island near station 43+00 contains a bypass flow channel that connects the main North Platte River to the Caldwell Slough. Aerial photography dating back 20 years does not indicate a bypass channel. This bypass channel will be filled with material to contain the bankfull discharge flows within the main channel to help maintain sediment transport capacity. The proposed pattern of the North Platte River below the flow bypass channel is thus enlarged to increase the flow capacity. At the lower end of Caldwell Slough near its confluence with the North Platte River, a step/pool feature is proposed to improve fishing diversity.

4.3 PROPOSED CHANNEL PROFILE

The facet slope and maximum depth values for the existing reach are compared to the proposed values in **Table 1**. The existing maximum depth values are low and are increased in the conceptual design to better define the low flow channel and to improve sediment transport capacity and aquatic habitats. However, the maximum depth values are limited by utility crossings as indicated in the proposed longitudinal profile (**Figure 5**). Furthermore, the proposed profile currently reflects the ideal design maximum depths; however, these depths may change once the underlying bedrock depths are mapped.

The bedrock and sewer pipeline near station 39+27 limits the lowering of the upstream bed profile; the proposed design cover over the 10-inch diameter sewer line is 0.75 ft. The 12-inch diameter sewer pipeline near station 84+04 limits the downstream lowering of the bed profile and the narrowing of the channel dimensions; the proposed design cover over the 12-inch sewer line is 0.25 ft. These constraints create two slightly different slopes of 0.0025 upstream of the 12-inch sewer line and the 130 Bridge and a slope of 0.0022 downstream of the sewer line at 84+04. The reach between the 130 bridge and the sewer line is a transitional zone with a designed cross-channel, double W-Weir structure to protect the bridge and control the grade. A 12-inch water line exists at station 72+53 with an associated elevation of 6770.6 ft. The proposed channel thalweg is designed at an elevation of 6773.61ft leaving 3.01 ft of cover over the line. To maintain this elevation, a J-Hook structure is proposed to help stabilize the bed and protect the integrity of the waterline.

A final design will require additional analyses of the existing utility lines. The minimum cover depths should be reviewed with the respective utility companies, which may impact the proposed design profile.

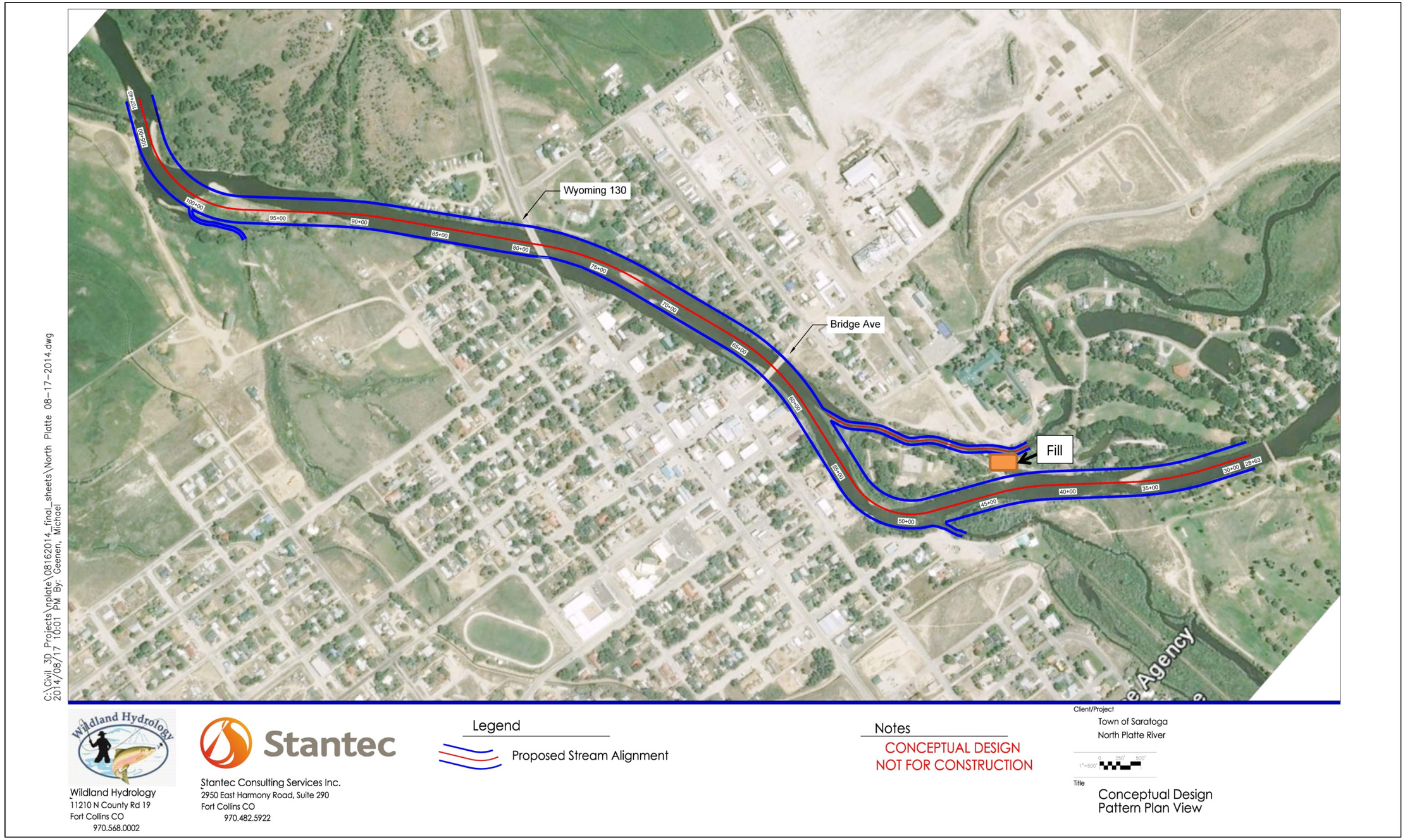

Figure 4. Proposed plan view design for the North Platte River through Saratoga, Wyoming.

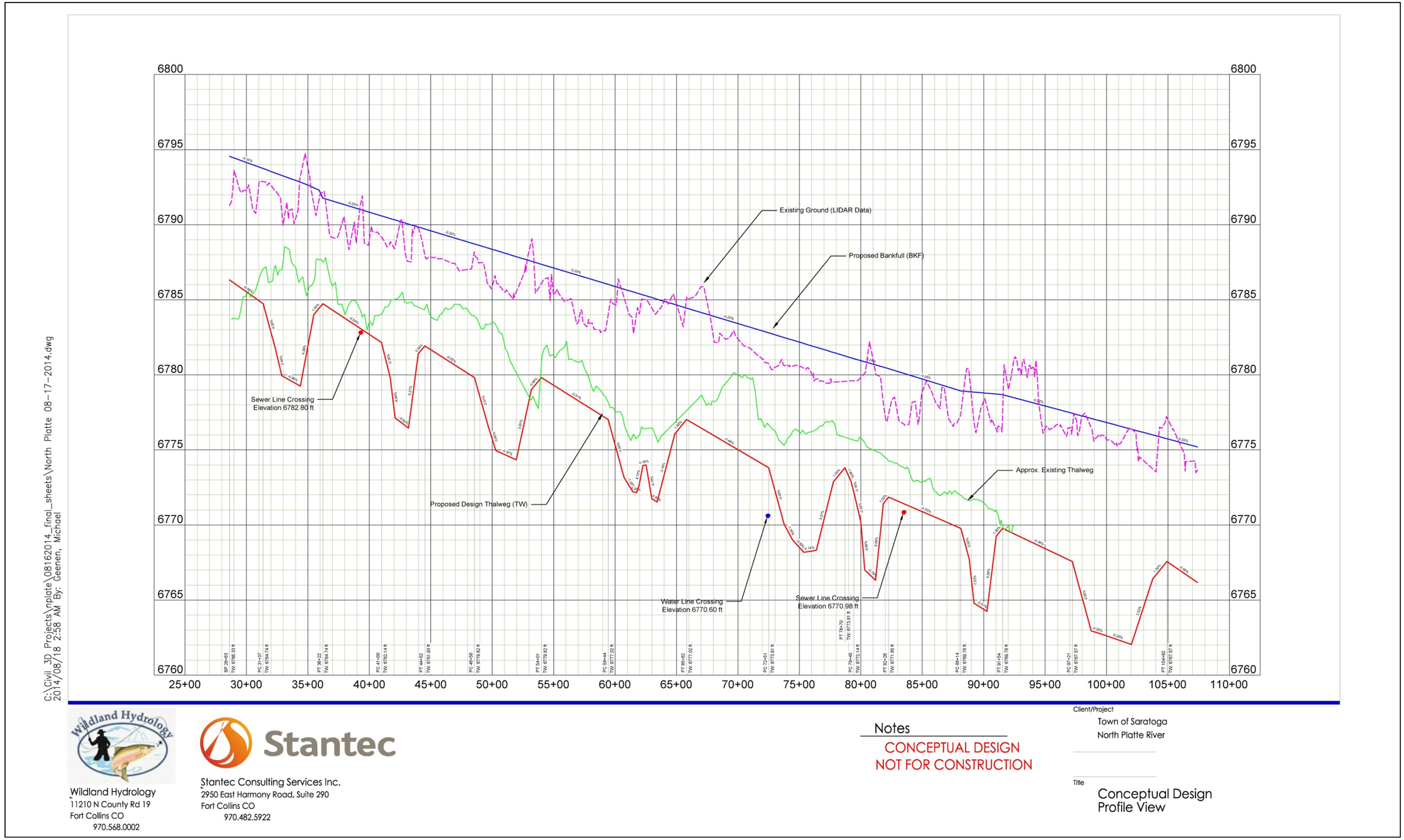

Figure 5. Proposed longitudinal profile design for the North Platte River through Saratoga, Wyoming.

4.4 FLOW HYDRAULICS

Sufficient energy is required to maintain a stable streambed and aquatic habitat and to transport sediment. Sediment transport is directly influenced by velocity and shear stress, which are products of slope and depth. The proposed flow hydraulics for the conceptual design result in increased velocity and shear stress by reducing the width/depth ratio and slightly decreasing the existing energy slope. **Table 3** summarizes the proposed bankfull mean velocity, shear stress, unit stream power (velocity multiplied by shear stress), and energy slope for the typical, upstream riffle. This data is used in the sediment competence and transport capacity computations.

Table 3. Hydraulic characteristics of the proposed stream channel for a typical riffle reach.

	Bankfull Mean Depth	Bankfull Slope	Mean Velocity	Shear Stress	Unit Stream Power
Riffle Cross-Section	5.3	0.0025	5.3 ft/sec	0.83 lbs/ft^2	4.4 lbs/ft/sec

4.5 SEDIMENT COMPETENCE

A sediment competence evaluation is necessary to determine if the proposed stream design has the ability to transport the largest particle sizes made available from its catchment based on the bankfull mean depth and slope. The assessment report included an evaluation of sediment competence for the existing reach and found that there was insufficient shear stress to transport the largest particle size of 177 mm found on a point bar from the bar sample, indicating aggradation. The analysis concluded that the existing stream can transport a 100 mm particle.

The proposed design increases the riffle mean depth to 5.3 ft (associated with a lower width/depth ratio of 34.0) and the slope to 0.0025, resulting in a shear stress of 0.83 lbs/ft^2. This shear stress has the ability to move a 150 mm particle, which is close to the existing 177 mm particle size. While 150 mm is not the largest particle being delivered by the catchment, this should significantly reduce the aggradation potential of the river.

4.6 SEDIMENT TRANSPORT CAPACITY

The geomorphic assessment included a sediment transport capacity evaluation using the FLOWSED and POWERSED models. This analysis indicated that the existing conditions of the North Platte River do not have sufficient energy to transport the total annual sediment yield being delivered by the watershed, resulting in channel aggradation. This in turn is causing a loss in channel capacity and an increase in flood stage.

The FLOWSED model used bedload and suspended sediment values measured at the bankfull discharge to determine the total annual sediment yield (tons/yr). The model indicated that 12,877 tons/yr of bedload and suspended sand (total sediment concentration minus the washload portion kept in suspension) sediment must be transported at the upstream limit of the study area (cross-section 1 or XS-1). However, at XS-17 located 7,345 ft downstream of XS-1 and between the Highway 130 and Bridge Street Bridges, the POWERSED model indicates that only 6,216.6 tons/yr of sediment can be transported due to the high width/depth ratio and mid-channel bar (**Table 4**). This indicates that potentially 6,666 tons/yr of sediment of the upstream yield is deposited between XS-1 and XS-17.

Furthermore, the geomorphic assessment indicated that the streambank erosion between XS-1 and XS-17 is approximately 2,121 tons/yr. This value represents the portion of sediment that can be deposited (approximately 20% of the total bank erosion is assumed to be the washload portion). The 2,121 tons/yr from streambank erosion can be added to the 6,666 tons/yr of sediment deposited between the reaches from the upstream supply, indicating potential deposition of 8,787 tons/yr (**Table 5**).

As a result of these computations, the average annual amount of aggradation in the existing reach is 0.17 ft. In ten years of normal runoff, the bed of the stream will potentially aggrade 1.65 ft from its current location; however, the amount of aggradation can be much greater with flood flows.

Under post-restoration conditions, the POWERSED model indicates slight aggradation of 363 tons/yr between the upstream location (associated with a 34 width/depth ratio and a 0.0025 slope) and the downstream location (associated with a 28 width/depth ratio and a 0.0022 slope). This aggradation will be on the order of 0.007 ft/yr during an average year and reduces the 10 year potential aggradation to 0.068 ft. While some aggradation will still occur, the rate will be significantly reduced from the existing conditions, resulting in a more sustainable river condition. It should be noted that it is also advisable to reduce the sediment supply from the accelerated streambank erosion immediately upstream prior to implementing the conceptual design through town.

Table 4. Annual sediment transport capacity for existing conditions and proposed conditions comparing the capacity at upstream and downstream locations.

Location	Total Annual Sediment Yield (tons/yr)	Suspended Sand (tons/yr)	Bedload (tons/yr)
POWERSED(a): XS-1 0+54 54 W/d	12,878.5	10,632.5	2,246.0
POWERSED(b): (cells) XS-17 72+91 82 W/d	6,212.6	4,023.6	2,188.9
Difference	6,665.9	6608.9	57.1
POWERSED(a): DESIGN 34 W/D Ratio 0.0025 Slope	14,197.0	11,438.1	2,758.9
POWERSED(b): DESIGN 28 W/D Ratio 0.0022 Slope	13,870.3	11,180.6	2,689.7
Difference	326.7	257.5	69.2

Table 5. Annual flood stage increases due to aggradation predicted from the FLOWSED/POWERSED models between the upstream and downstream reach locations.

	Existing Condition	Post-Restoration
Sediment aggradation from upstream sediment yield	6,666 tons/yr	327 tons/yr
Sediment aggradation from streambank erosion (minus washload portion)	2,121tons/yr	36.2 tons/yr
Total potential aggradation between upstream and downstream reaches	8,787 tons/yr	363 tons/yr
Depth of aggradation or flood stage increase per year	0.16 ft	0.007 ft
Depth of aggradation or flood stage increase per 10 years	1.65 ft	0.068 ft

4.7 FLOOD RISK

The flood risk potential for the town of Saratoga and private land owners along the North Platte River through Saratoga is dependent on the discharge of water and the sediment that is being produced by this 2,840 mi^2 watershed area. The existing channel configuration (a result of previous channel manipulations and dredging that were intended to reduce flood risk through town) promotes aggradation and increases the flood stage through town. The proposed design will help decrease the flood risk through town compared to existing conditions by reducing the width/depth ratio and excess sediment deposition.

Directly above the Highway 130 Bridge, the existing channel conveys a discharge of 5,200 cfs with a water surface elevation (WSE) of 9781.86 ft (**Figure 6**); the discharge has a flood recurrence interval of 1.55 yr. For the same flow, the design cross-section with a lower width/depth ratio has an associated water surface elevation of 9781.7 ft (**Figure 7**), which represents a reduction in flood stage of 0.16 ft.

The low bank on river right has an elevation of 6784.97 ft and will contain a discharge of 13,200 cfs, corresponding to an approximate 7- yr flood recurrence interval. The same feature on the design cross-section has capacity for an additional 600 cfs, for a total of 13,800 cfs corresponding to an 8-yr flood recurrence interval.

The largest discharge of record was 16,900 cfs recorded on June 9th, 2011. This flow rate represents an approximate 25-yr flow event with a predicted water surface elevation of 6786.1 ft for existing conditions and 6786.0 ft with the proposed design. The 100-yr discharge was predicted to be 24,000 cfs with a calculated water surface elevation of 6788.01 ft for existing conditions and 6787.9 ft with the proposed design.

The conceptual design shows a minimal reduction in flood stage of ~ 0.1 ft at the Highway 130 Bridge and 0.0–0.3 ft flood stage reduction for the 100-yr storm over the entire project reach. The higher frequency floods will also have a slight reduction in flood stage. The biggest flood-reduction advantage is a result of the increased sediment transport capacity that can be achieved through geomorphic restoration by narrowing the channel and reducing sediment deposition and the sediment supply from streambank erosion.

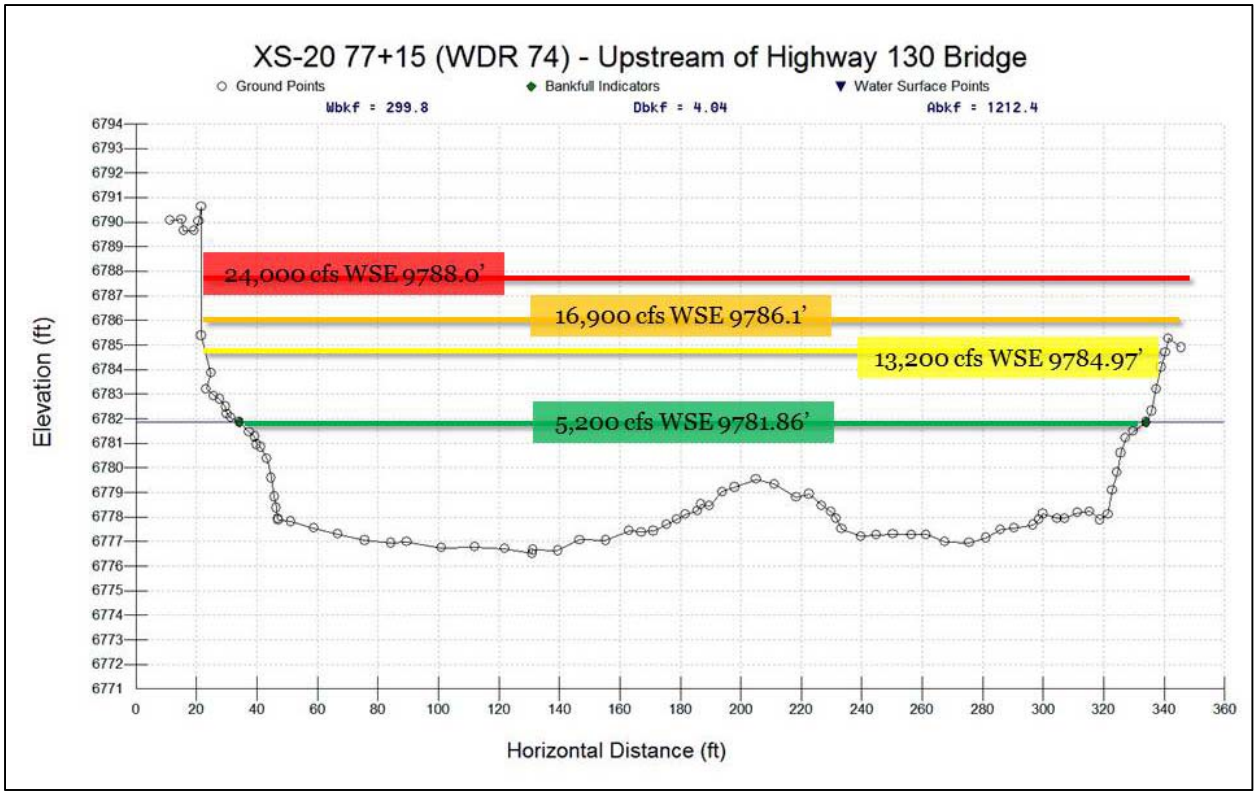

Figure 6. Existing flood stages at various discharges upstream of Highway 130 Bridge.

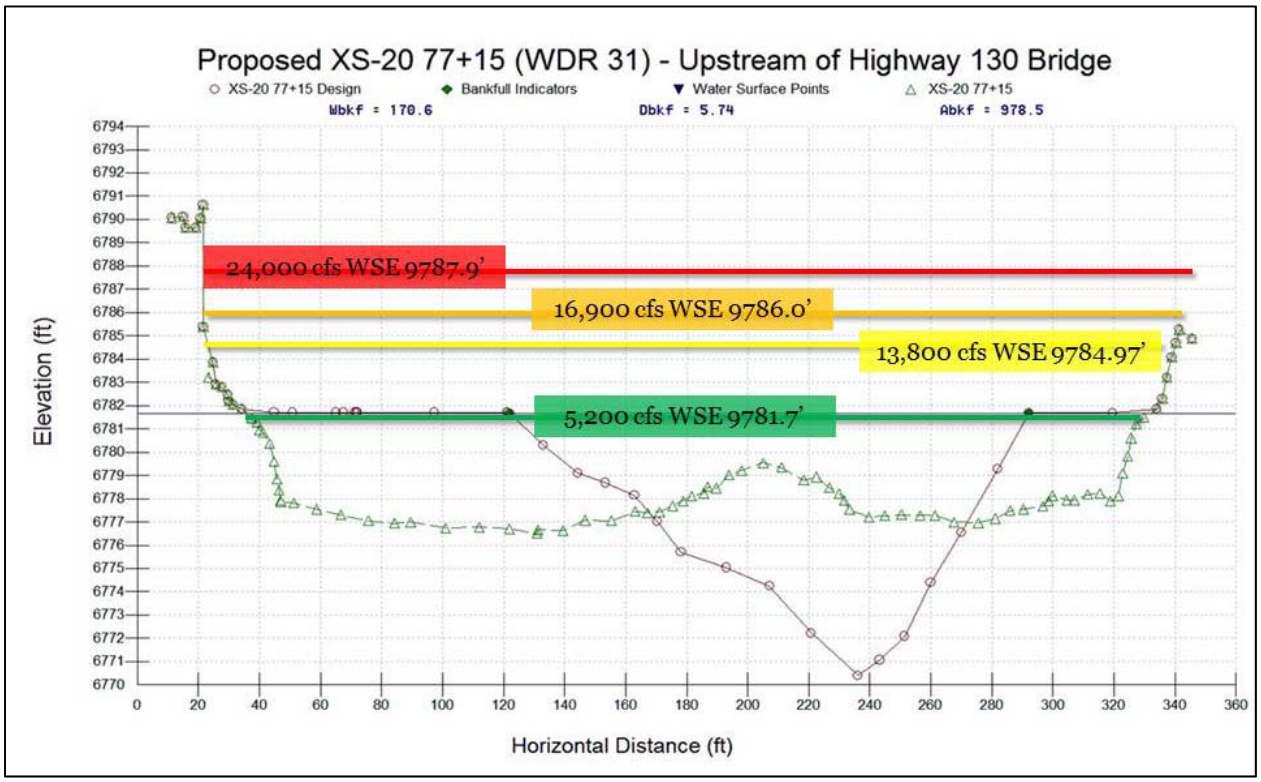

Figure 7. Proposed flood stages at various discharges upstream of Highway 130 Bridge.

4.8 CHANNEL STABILITY & FISH HABITAT ENHANCEMENT STRUCTURES

Coincident with proper channel morphology design, the use of restoration structures are necessary to allow time for the riparian vegetation to establish, reduce streambank erosion, dissipate flow energy, provide grade control, provide aquatic habitats, protect infrastructure, and maintain floodplain connectivity. The long-term goal of the conceptual design is to allow the river to adjust within the variability of natural systems; thus the channel boundary is not "hardened" throughout its length.

The following proposed structures are recommended in the conceptual design:

a) Toe Wood for streambank stabilization and an undercut bank for cover using wood and transplanted vegetation
b) J-Hook Vanes for aquatic habitat, boat access locations, and near-bank stress reduction thereby reducing streambank erosion
c) Cross-Vanes for grade control, fish habitat, energy dissipation, and flow diversions
d) Converging Rock Clusters for grade control, energy dissipation, and holding cover in riffles
e) W–Weir for grade control, near-bank stress reduction, holding cover, and bridge pier protection

The proposed locations of the various structures are depicted in **Figure 8.** The structures use native materials and have been designed and successfully implemented by the design team on large rivers to meet the aforementioned objectives. Discussion and examples of each structure are also provided.

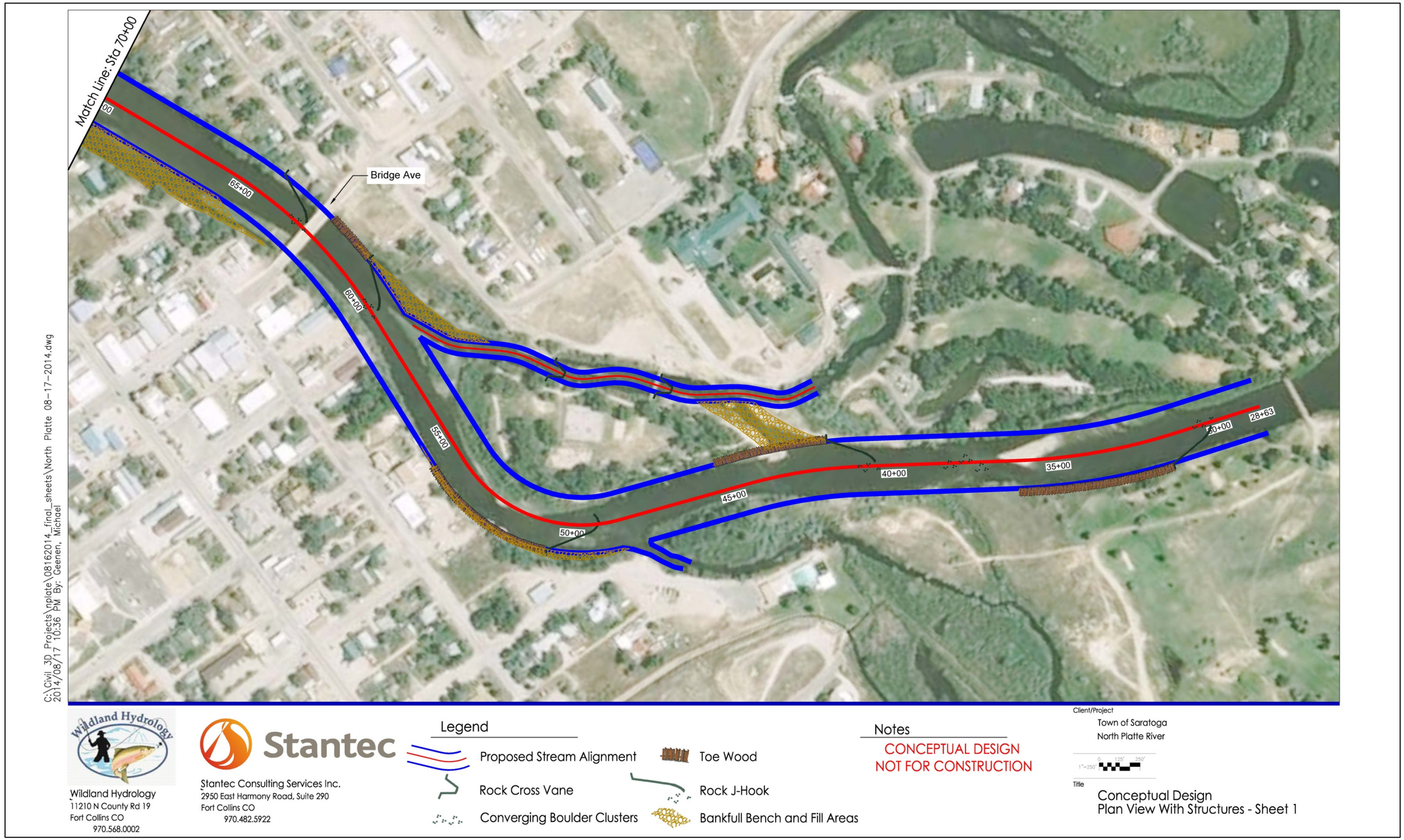

Figure 8a. Proposed plan view layout with structure placement for stations 28+64 to 70+00 for the North Platte River through Saratoga, Wyoming.

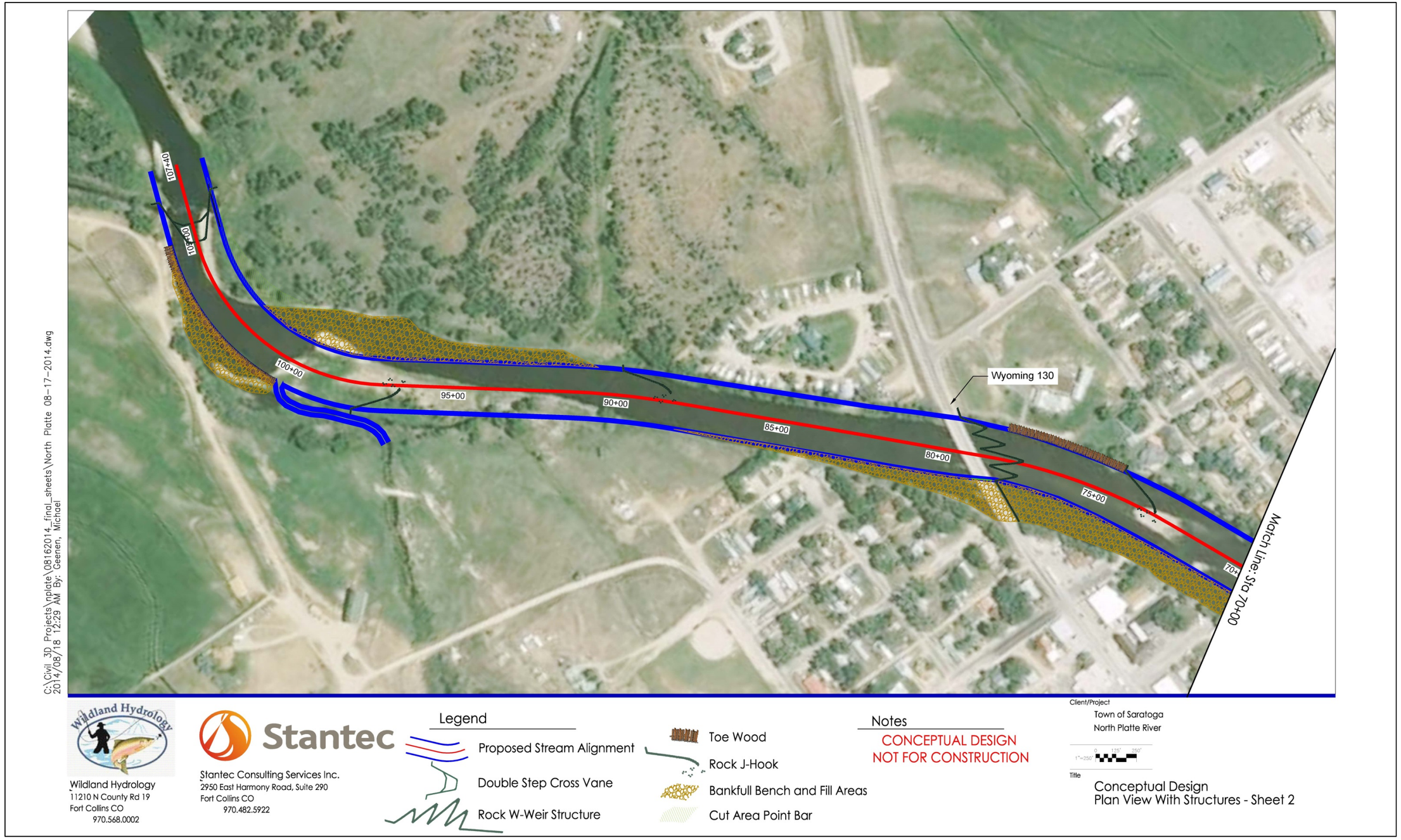

Figure 8b. Proposed plan view layout with structure placement for stations 70+00 to 107+40 for the North Platte River through Saratoga, Wyoming.

4.8.1 Toe Wood

The Toe Wood structure is designed to stabilize streambanks and maintain a low width/depth ratio of the design channel. The advantages of this structure are the availability of the toe wood material, the associated lower costs, and a more natural appearance than traditional stabilization materials, such as rock rip-rap, gabions, concrete, and interlocking block; no rocks are used for this structure. This structure also increases the macro-invertebrate habitat, introduces a carbon source to the system, and enhances aquatic habitat with overhead and instream over.

This structure incorporates native woody material into a submerged undercut bank to replicate natural streambanks. The toe wood is placed at the toe of eroding streambanks on the lower one-third to one-half of the bank to ensure the wood is submerged year round to prevent wood deterioration. The structure is also used in conjunction with the design of a bankfull bench rather than placed against a vertical terrace or colluvial slope. The bankfull bench reduces convergence against the upper bank and places the vegetation on the bench in a higher water table site and therefore improves the vegetative survival rates. Vegetation transplants are placed over the toe wood up to the bankfull stage.

Variations in the Toe Wood structure are available depending on the local vegetation available (**Figure 9**). One option is to use cuttings and transplanted sod mats that are staked and held down by interweaving shroud line. Another option uses woody transplants, such as willow, alder, cottonwood, or dogwood, instead of the cuttings and sod mats. Where sod mats and woody transplants are unavailable, cuttings are used with "burrito" soil lifts. Photographs comparing the pre-treatment condition with the post-installation of Toe Wood on larger rivers are shown in **Figures 10–13**.

The locations of Toe Wood placement on the North Platte River through Saratoga are indicated in **Figure 8**. The Toe Wood is designed with a bankfull bench against the existing high banks on the outside meander bends and will add flow resistance to protect the streambank from erosion and will provide excellent instream cover.

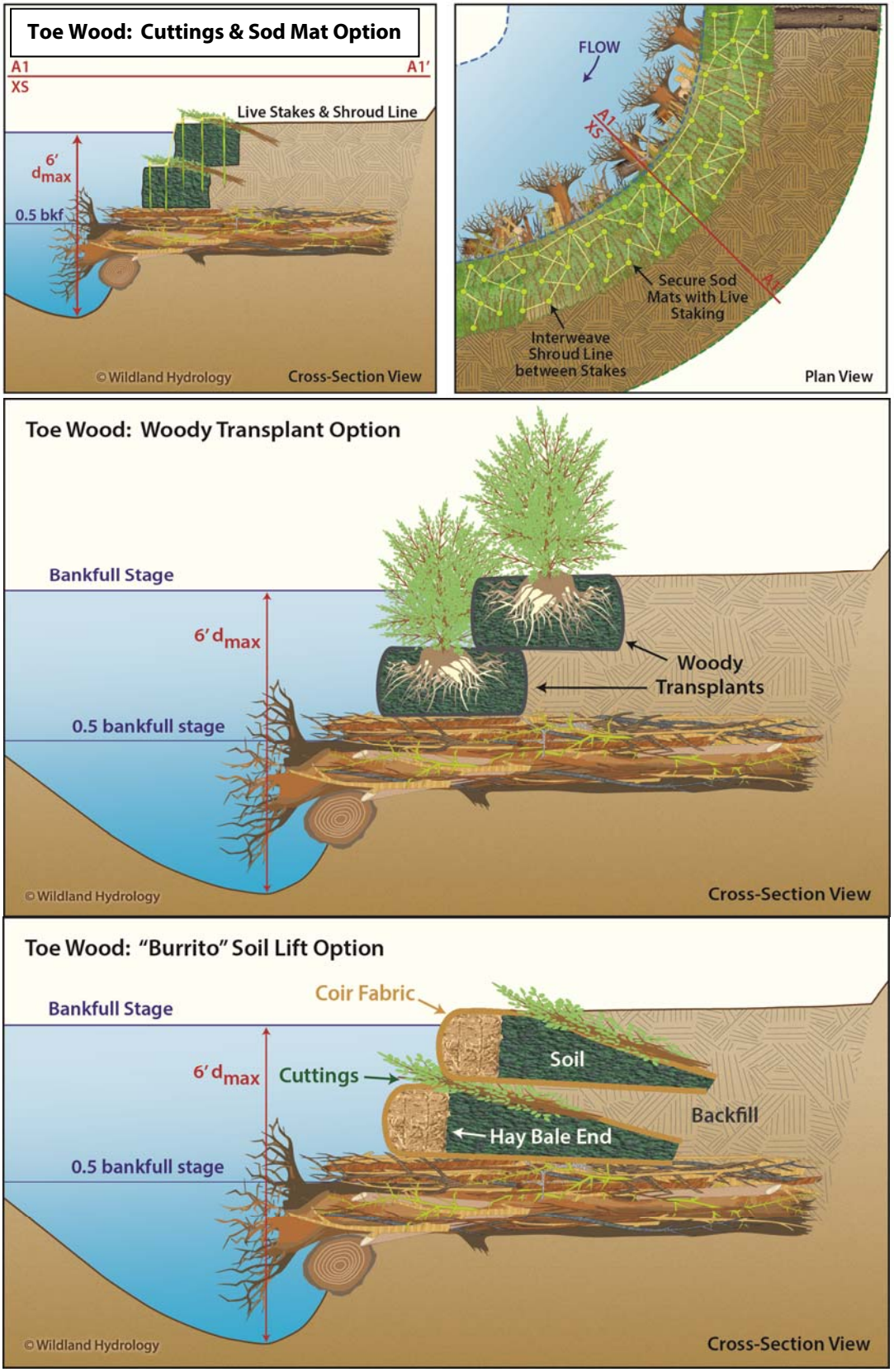

Figure 9. The Toe Wood conceptual design showing different options for the vegetation covering.

Figure 10. (a) pre-restoration condition of the Bitterroot River, Montana, and (b) the post-restoration condition showing Toe Wood to stabilize streambanks and enhance habitat; the pool is 18.0 ft deep.

Figure 11. (a) pre-restoration condition of the Bitterroot River, Montana, and (b) the post-restoration condition showing a constructed bankfull bench against glacial outwash terrace and Toe Wood to stabilize streambanks and enhance habitat; no rocks were used and the bank is intact following four years of major flooding following construction.

Figure 12. (a) pre-restoration condition, and (b) the post-restoration condition showing a constructed bankfull bench and submerged Toe Wood against a high glacial outwash terrace bank on a braided reach of the Bitterroot River, Montana.

Figure 13. (a) pre-restoration condition of the Big Wood River, Idaho, and (b) the post-restoration condition showing Toe Wood and transplanted willows.

4.8.2 Rock J-Hook Vane

The Rock J-Hook Vane redirects high velocity gradients away from the streambank and places the erosive currents in the center of the stream to decrease near-bank shear stress and thereby reduce streambank erosion (**Figure 14**); these conditions also allow for access points for fisherman and boaters. The streambank area protected is calculated as three times the length of the vane arm. The structure also creates longer, wider, and deeper pools and maintains bed features including glides that are important for spawning. The structure also creates aquatic habitat and provides holding cover. This structure is constructed with the use of a bankfull bench. Examples of constructed J-Hook Vanes are shown in **Figures 15–17.**

The locations of the J-Hook Vane in the conceptual restoration design of the North Platte River are included in **Figure 8**. The J-Hook Vane near Veteran's Island at the east end of Walnut Avenue is designed to provide a boat access point. Additional potential boat access points are on the right bank, station 59+00 to 62+00, near the proposed SGT Pickett Park, and on the left bank, station 63+00 to 77+00, between the Bridge Street and Highway 130 Bridges.

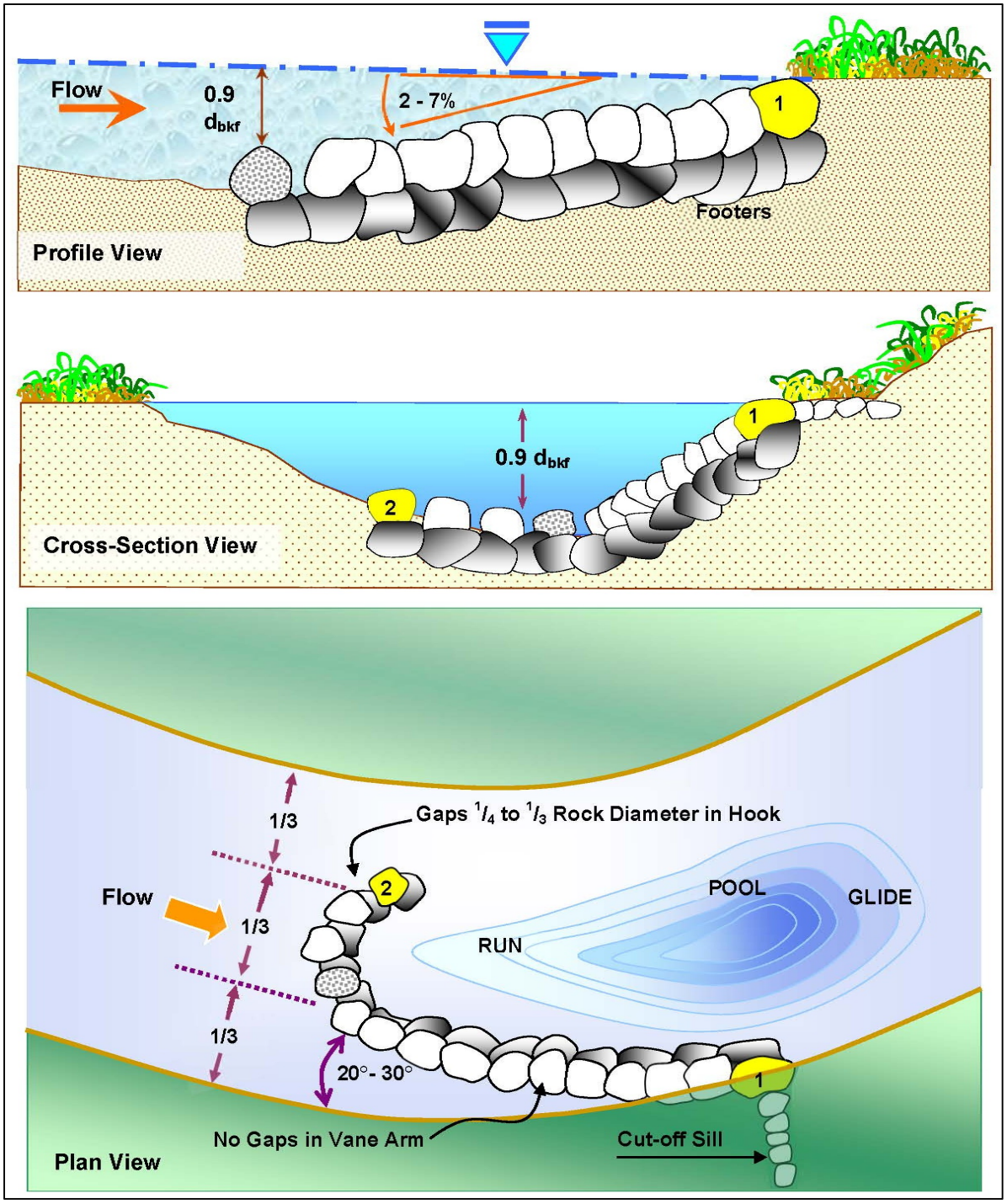

Figure 14. Longitudinal, cross-section, and plan views of the Rock J-Hook Vane.

Figure 15. Log J-Hook Vane, Weminuche Creek, Colorado.

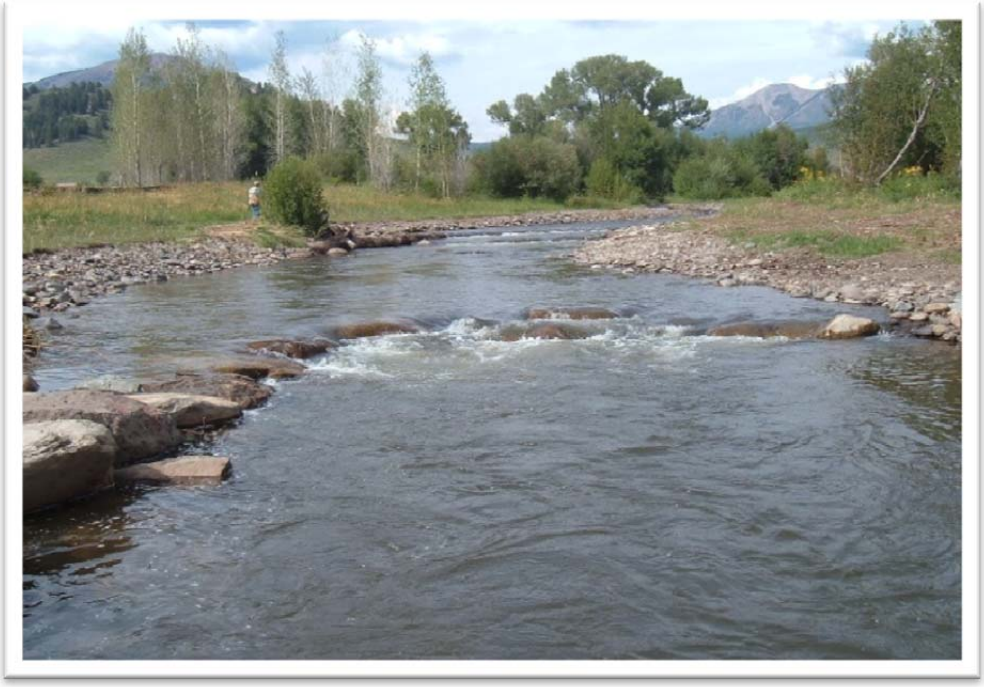

Figure 16. Rock J-Hook Vane, Ohio Creek, Colorado.

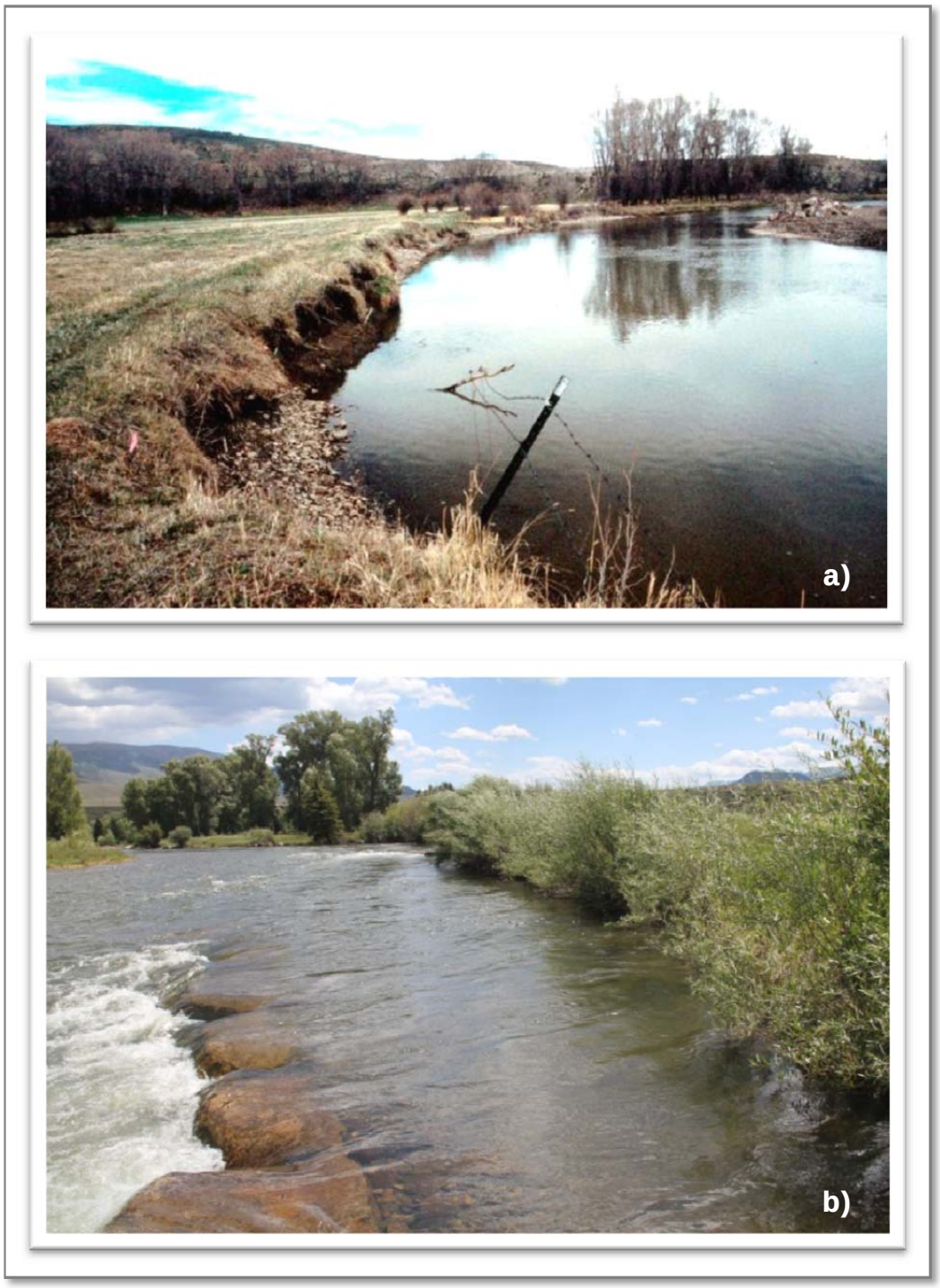

Figure 17. (a) pre-restoration condition of the Blue River, Colorado, looking downstream at group of cottonwood trees, and (b) post-restoration condition 18 years after photo in (a) using a Rock J-Hook Vane and willow transplants, looking upstream at same group of cottonwood trees.

4.8.3 Toe Wood & Rock J-Hook Vane Combination

Rock J-Hook Vanes are used with Toe Wood at locations where Toe Wood can be installed (**Figure 18**). The Rock J-Hook Vane and Toe Wood are used in combination for several reasons:

1. The Rock J-Hook Vane provides protection of the Toe Wood from flanking
2. The Rock J-Hook Vane accentuates the downstream pool and keeps fine sediment from accumulating in the pool
3. The Rock J-Hook Vane creates a seam of slow to fast water that provides adequate feeding and resting zones for fish
4. The Toe Wood provides excellent instream cover in the upper pool created by the Rock J-Hook Vane

Figure 19 provides an example of the implemented structures.

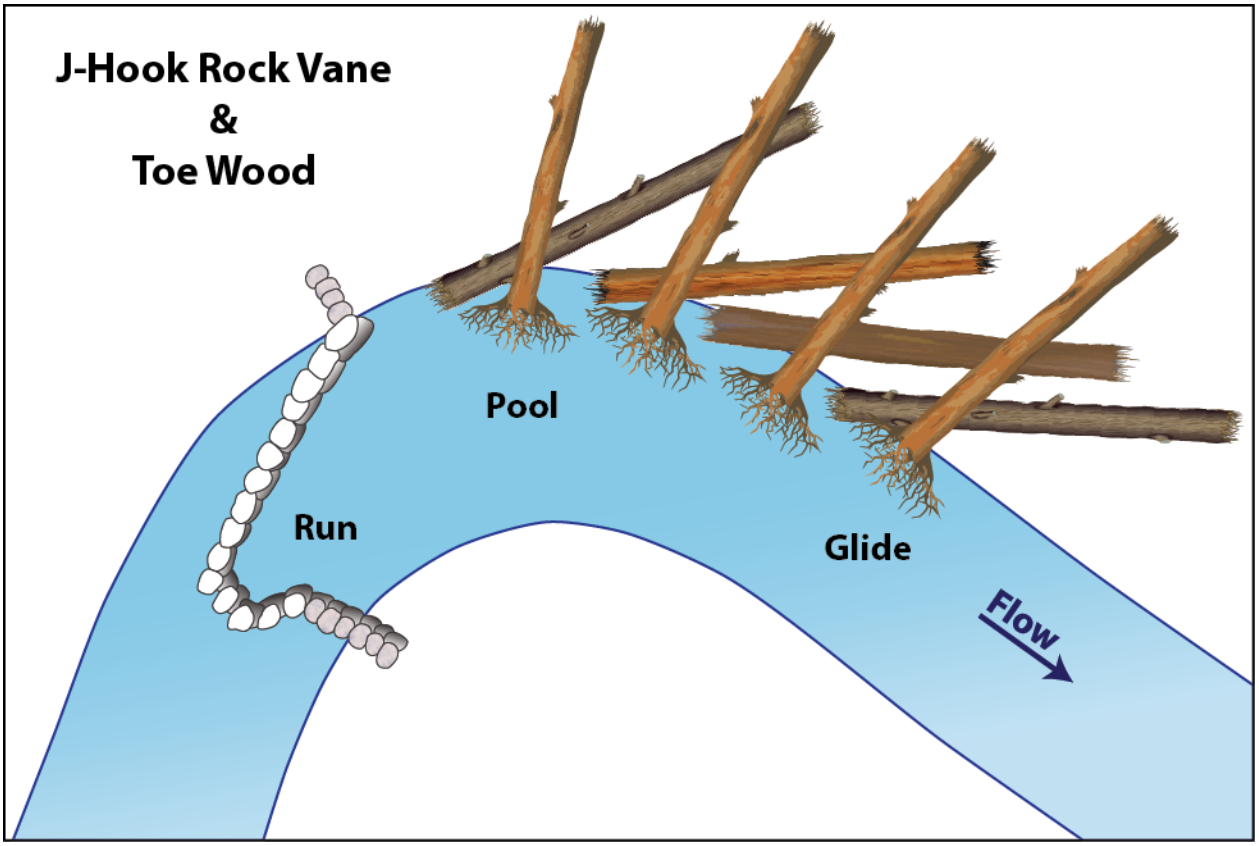

Figure 18. The use of a Rock J-Hook Vane in conjunction with Toe Wood.

Figure 19. A Rock J-Hook Vane and Toe Wood at 60% bankfull stage, Blue River, Colorado.

4.8.4 Rock Cross-Vane

Cross-Vanes are used to control the grade, reduce the near-bank stress, and provide aquatic habitat. Cross-Vanes are particularly suited as a diversion structure as they provide the stage needed for water diversions without raising local flood stage (**Figure 20**). The vane arm provides a differential head that presents water to the headgate even at low flows, yet prevents washout during high flows. Furthermore, the sediment that is normally trapped against the headgate or released into the diversion canal is transported back to the river before it is delivered to the canal. A screen can also be added to prevent fish from migrating into the ditch. **Figure 21** and **Figure 22** show examples of this diversion structure.

A Cross-Vane diversion with a headgate and sediment sluice is proposed for the Pick Ditch Diversion at the end of the project reach (**Figure 8**). Several Cross-Vanes are also proposed to create the step/pool features on the Caldwell Slough that will appear as in-line oxbow channels (**Figure 8**).

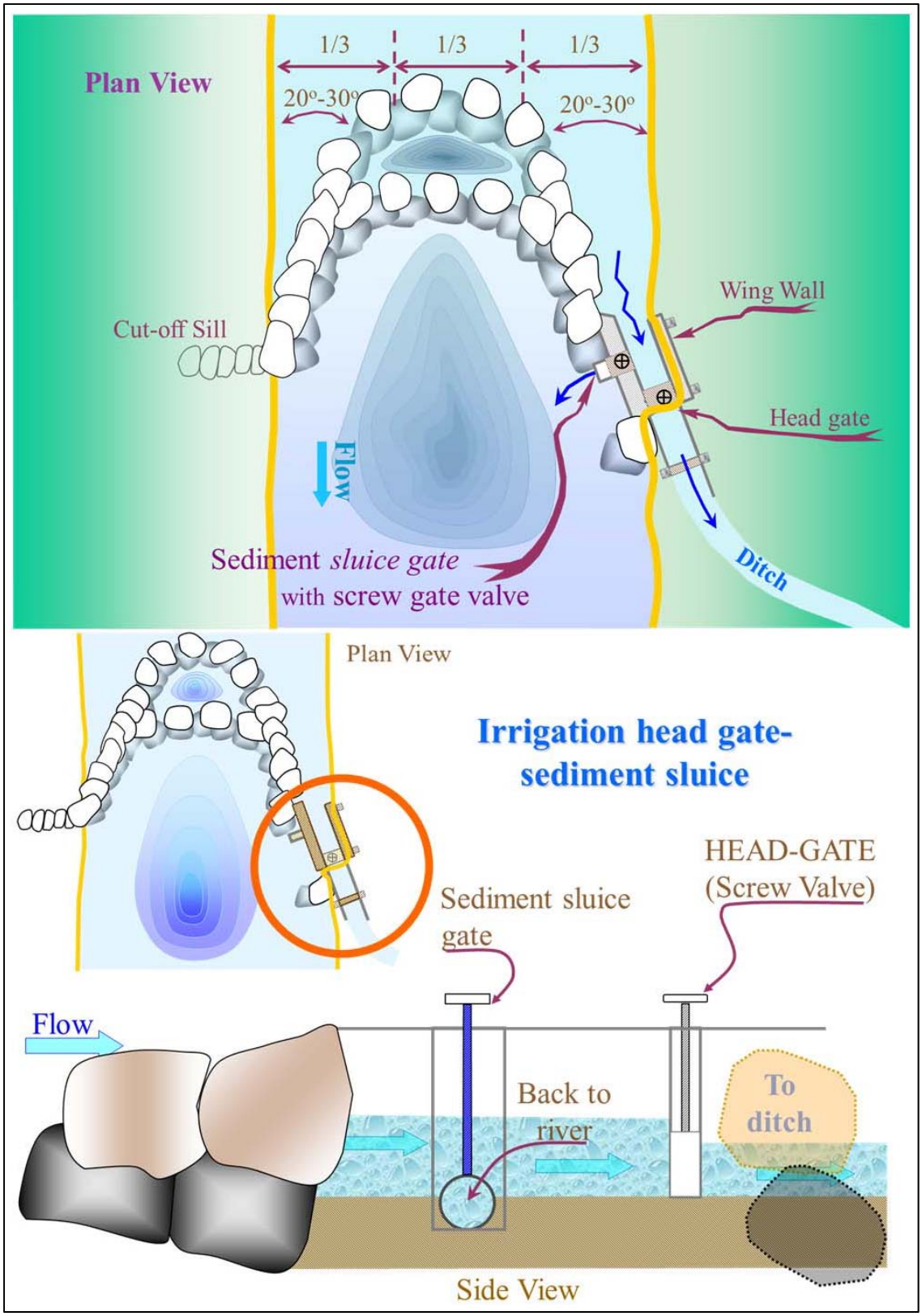

Figure 2. Conceptual design of the Rock Cross-Vane used for a diversion with a headgate and sediment sluice.

Figure 21. A step-pool Cross-Vane showing the differential head of water presented to the headgate in **Figure 22**, Blue River, Colorado.

Figure 22. The sediment sluice with screw gate valve on the left whose invert is lower than the headgate with the screw gate valve on the right.

4.8.5 W-Weir

The W-Weir (**Figure 23**) provides grade control, redirects currents, reduces near bank shear stress to decrease streambank erosion, and converges flow to create a downstream pool for instream holding cover. The W-Weir is also designed to reduce bridge pier scour by increasing the energy through the center on the bridge cells while reducing the energy on the piers (**Figure 24**).

This structure can also be implemented as a double W-Weir that has four thalwegs instead of two to protect multiple bridge piers, such as the case of the Highway 130 Bridge (**Figure 25**). Currently the Highway 130 Bridge presents several geomorphic, hydrologic, and structural problems, including:

1. Excessive bridge pier scour due to the angle of approach and flow convergence
2. Excess sediment deposition and aggradation from the high width/depth ratio of the bridge design
3. Boater safety issues as the low flow currents travel perpendicular to the bridge piers

The proposed double W-Weir structure on the North Platte River will have four low points to protect the bridge piers where flows will concentrate into the center of the cells between the bridge piers (**Figure 25**). The double W-Weir along with the channel realignment will also secure a more favorable angle of approach and will create velocity vectors that pull boaters to the center of the cells and away from the piers. Last, the width of the channel will be reduced by 43% (the bankfull channel will be contained through four of the seven cells) allowing for more stream power to transport sediment through the reach; the remaining three cells will be used as a floodplain where flood waters can access the full width of the bridge.

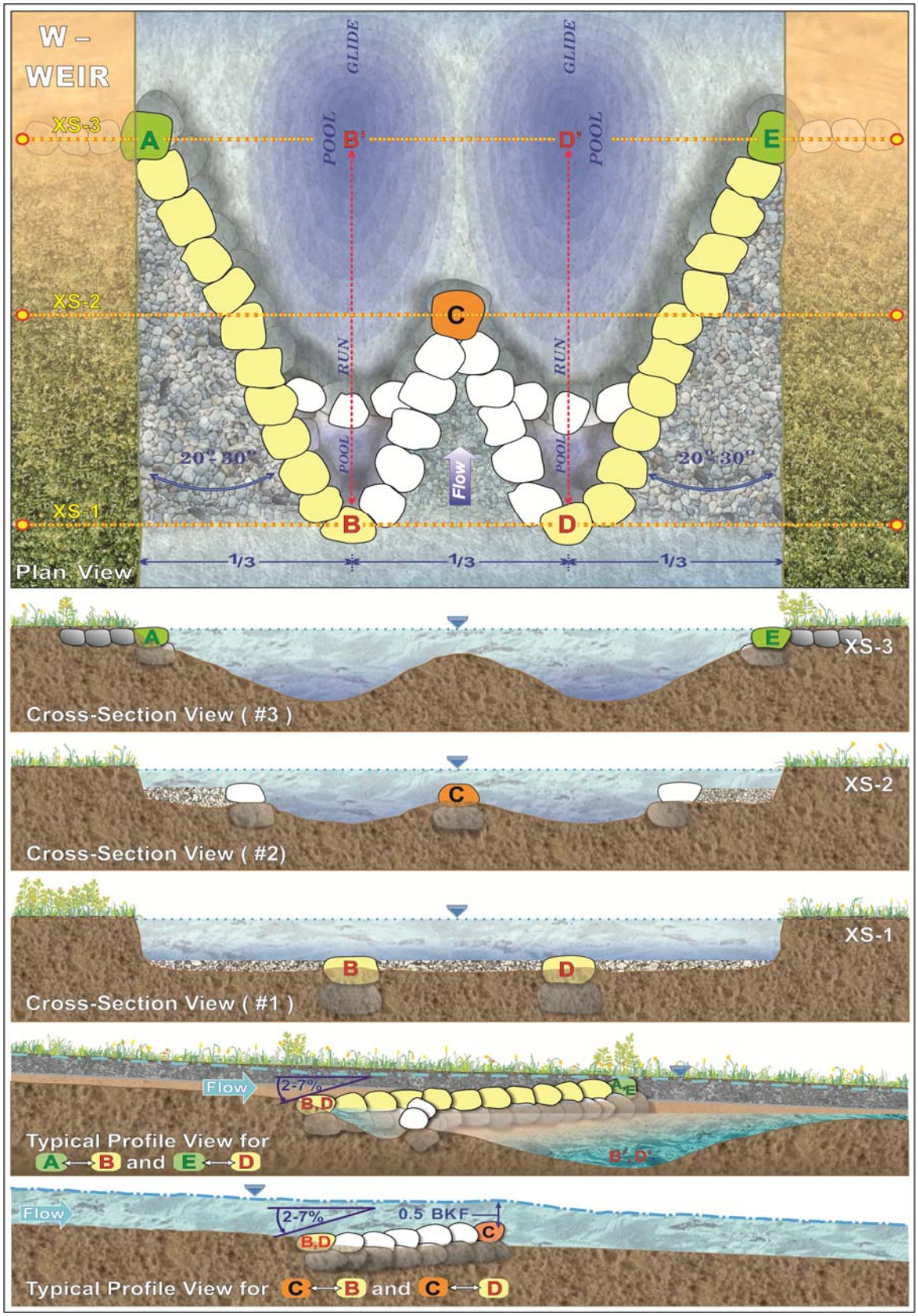

Figure 3. W-Weir conceptual detail.

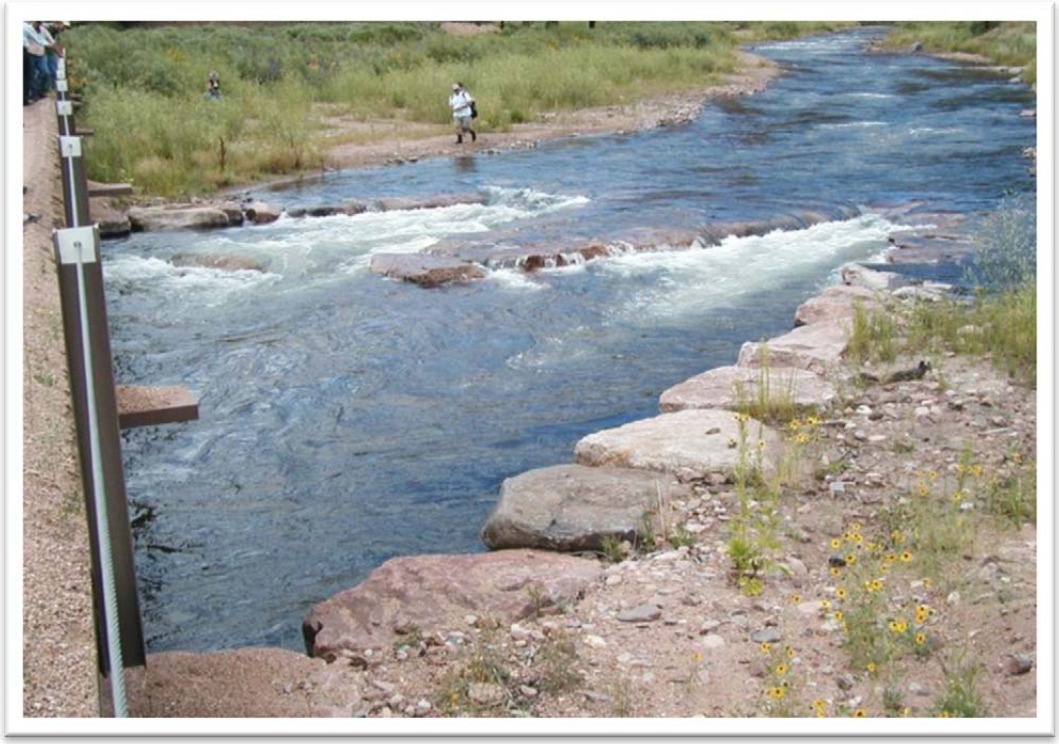

Figure 24. A W-Weir designed to reduce bridge pier scour.

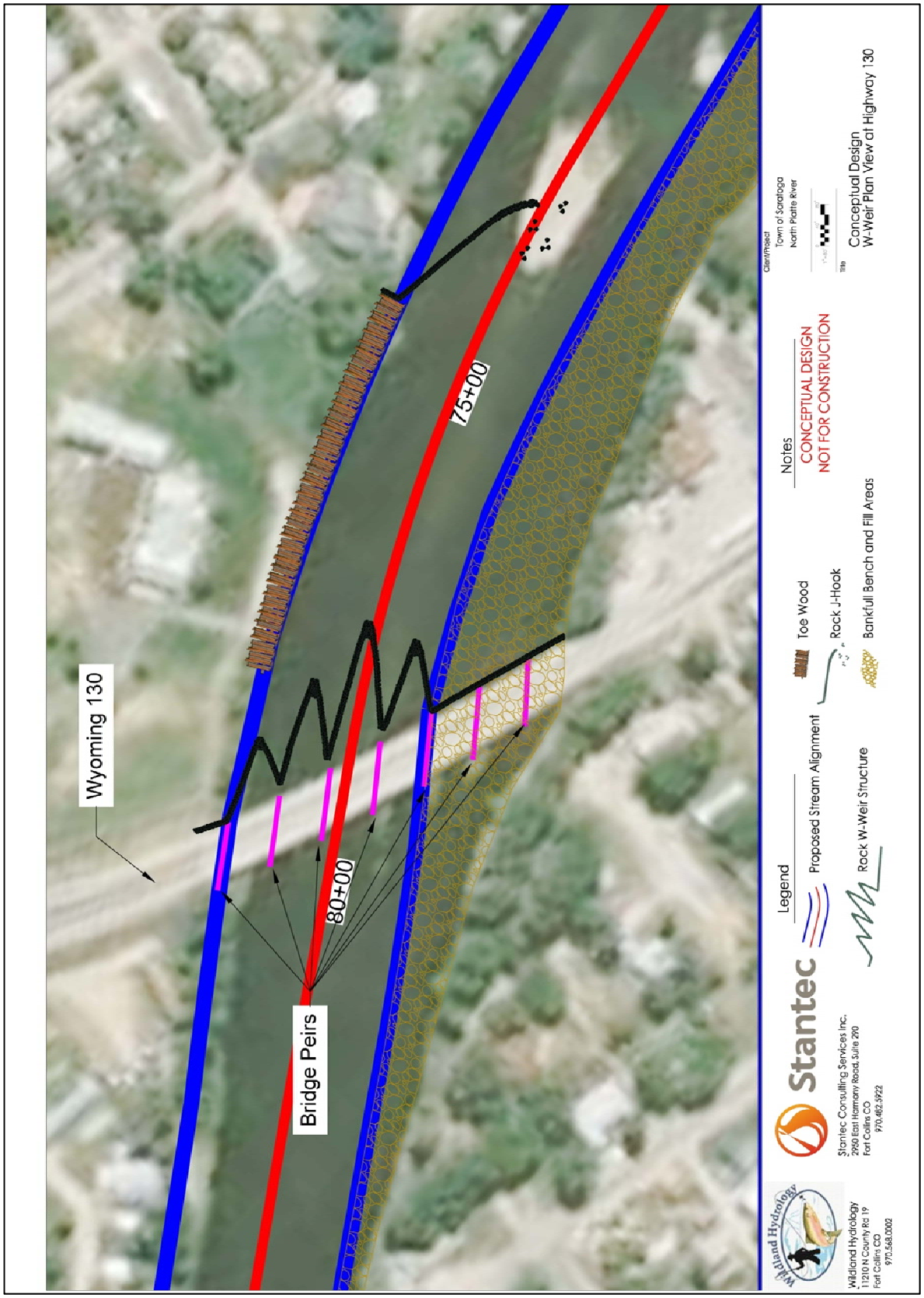

Figure 25. The double W-Weir designed on the North Platte River through Saratoga.

4.8.6 Converging Rock Clusters

Converging Rock Clusters (**Figure 26**) dissipate energy and provide grade control at the head of riffles to keep the facet slopes of the glide and pool flat and the riffle or rapid steep. The rocks must be submerged below half of the bankfull stage. Converging Rock Clusters also create pocket water pool habitat for cover in riffle reaches. **Figure 27** and **Figure 28** provide examples of installed Converging Rock Clusters.

The plan view of the conceptual design for the North Platte River through Saratoga (**Figure 8**) shows the placement of the Converging Rock Clusters.

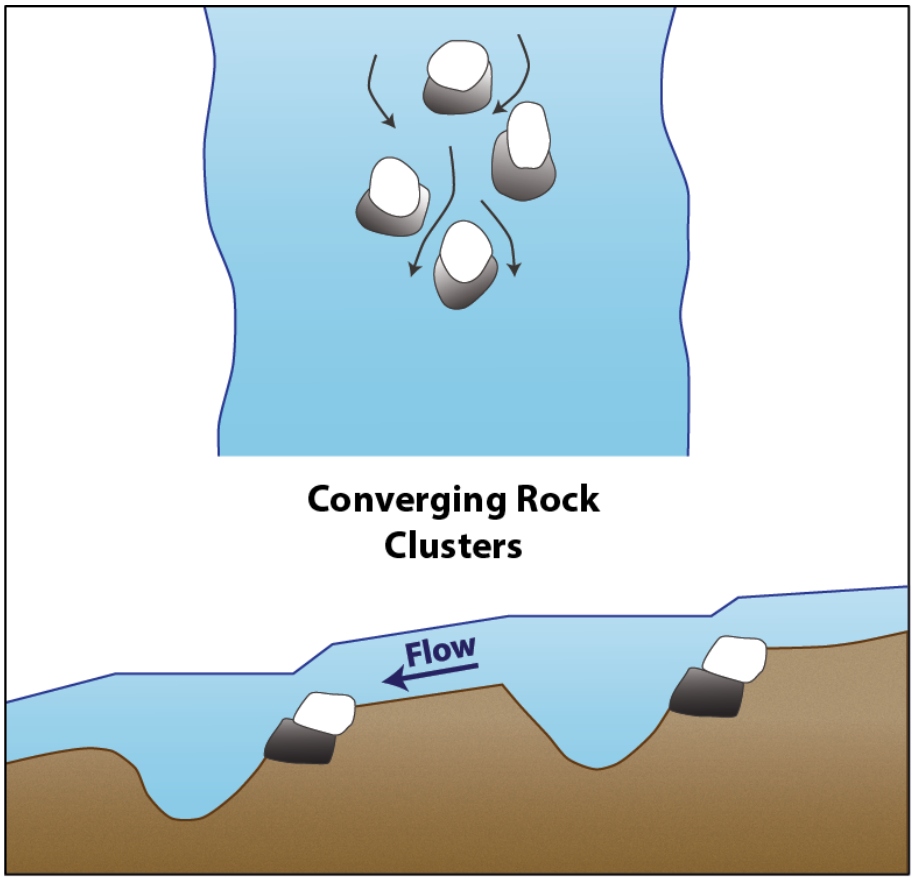

Figure 26. Plan and profile views of converging rock clusters, showing pocket water pool habitat for cover in riffle reaches.

Figure 27. Installed Converging Rock Clusters shown at low flow on the Laramie River, Colorado. These structures provide grade control and create excellent holding cover for fish.

Figure 28. Converging Rock Clusters installed on Crystal Creek, Idaho.

4.9 REVEGETATION, TRANSPLANTS, & MANAGEMENT

The protection and management of the riparian corridor is critical for the sustainability and functioning of the restoration. A detailed riparian management plan will need to be developed as part of the detailed design and implementation plan. A few recommendations related to the riparian vegetation management are as follows:

- Remove invasive species where practical in areas of transplanting and re-establishment
- Re-use all appropriate, native riparian and wetland vegetation as sod mats over Toe Wood or newly created streambanks
- Transplant willows, cottonwoods, and other riparian species so that the root balls are at an elevation at or below the low water elevation
- Cut whips from the canopy of transplants or other appropriate donor areas and install within 6.0–12.0 in. of the low water surface elevation (**Figure 29**)

Figure 29. Willow Whip sprouting through a sod mat transplant.

4.10 LIMITING FACTORS ANALYSIS OF FISHERIES

The geomorphic assessment report summarized the limiting factors analysis of the fisheries and suggested potential habitat improvements. The design solutions to improve aquatic habitat based on the limiting factors analysis are provided below:

- Improve pool quality by deepening the pools from 7.57 to 15.91 ft, increasing pool volumes for holding and over wintering, and decreasing the pool-to-pool spacing from 1,983 ft to 950 ft
- Steepen the riffle slopes from a minimum of 0.001 to 0.004 and narrow the riffle widths from 305 to 180 ft
- Narrow the low flow channel width from 173 to 84 ft to improve connectivity
- Reduce streambank erosion from 0.29 to 0.001 tons/ft/yr
- Increase the sediment transport capacity by decreasing the width/depth ratio and increasing the channel slope
- Create 100 ft wide floodplains within the old channel for riparian plants to be transplanted and colonized creating a natural riparian buffer
- Provide overhead cover with appropriate structures and by reintroducing a natural willow and cottonwood community

4.11 PROPOSED WETLAND IMPACTS

The majority of conceptual design work is to be completed within the existing channel boundaries and therefore minimizes the potential impacts to wetlands. However, less than 3.4 acres of wetlands may be disturbed associated with the following:

- 1.05 acres associated with the grading of Veteran's Island on the right bank of the river from stations 46+00 to 58+00
- 2.05 acres associated with the proposed re-alignment of the North Platte River on the Left bank from station 90+00 to 100+00
- 0.28 acres associated with the grading of the right bank of the river from station 102+00 to 106+00

Vegetation will be harvested and used for transplanting from all disturbed wetland areas that are free from invasive species. Furthermore, there is opportunity to potentially create at least 4.0 acres of wetlands and enhance at least 0.5 acres.

A formal wetland delineation within the project area has not been conducted, and therefore a detailed restoration design would need to verify the potential impacts and enhancements to the wetlands.

4.12 QUANTITIES & ESTIMATED COSTS

The conceptual design restores approximately 7,800 ft of the North Platte River and 1,200 ft of the Caldwell Slough. The estimated constructions costs are $400–600 per lineal foot for the North Platte River and $75–125 per lineal foot for the step/pool structures (cross-vanes) proposed on Caldwell Slough. Excavation quantities assume that the material is locally balanced in the range of approximately 130,000–180,000 yds^3.

The boulders needed for the structures are estimated at 5,730 tons (2–3 tons per boulder). Approximately 3,500 lineal feet of Toe Wood is proposed associated with approximately 14,000 yds^3 of woody material, including trees with root wads, logs, and debris. Depending on the availability, location, and haul distances, the costs can vary greatly. Beetle-kill pine trees on adjacent National Forest or BLM lands can possibly be used for the Toe Wood material.

The overall construction costs are estimated at 3.2 – 4.8 million dollars. These estimates do not account for utilities as the design assumes adequate cover over buried utility lines. The estimated costs also do not account for additional improvements to bridges or levees.

5.0 DESIGN ASSUMPTIONS

Specific design assumptions are listed below:

1. The proposed thalweg elevation below the Pick Ditch diversion could be potentially lowered to 6767.0 with a bankfull stage of 6776.0. Additional survey data will need to be collected and analyzed for a final design.
2. The functionality of the Pick Ditch diversion can be maintained with the lower, main channel water surface and an increase in sufficient stage (differential head) of the vane arm in the Cross-Vane structure. The diverted flow requirements of the Pick Ditch need to be analyzed for a final design.
3. Bedrock will be deeper than the design bed profile. Additional geotechnical investigation will need to be completed for a final design.
4. Utilities including sewer lines, water lines, phone conduit and gas line casings require a minimum depth of cover of 3.0–6.0 in. on the bottom of the North Platte River. Additional cooling calculations and buoyancy calculations are necessary for a final design.
5. The pedestrian bridge could be modified or rebuilt if needed. Additional engineering computations and communications with the town and the public are necessary for a final design.
6. The existing bridge footings have not been compromised by past flooding.

7. Veteran's Island can be slightly adjusted and the historical structure can be moved to another location on Veteran's Island if needed to allow for increased flood capacity.
8. Gage data is accurate and appropriate for design purposes.
9. Sediment data collected at high water is representative to predict sediment rating curves of the North Platte River for use in the FLOWSED/POWERSED models.
10. The end of the project will be able to sustain an energy slope sufficient to prevent backwater.
11. Berms and levees will be adjusted and stabilized only to the extent that is needed to accommodate the restoration design. This project does not include improvements to berms and levees for flood protection.

6.0 DOES THE DESIGN MEET THE STATED OBJECTIVES?

It is of key importance to evaluate if the proposed conceptual design will potentially meet the stated objectives. The following sections discuss how the conceptual design can potentially meet the intended objectives:

Objective #1: Design a self-sustaining, natural, stable river

This project objective is addressed by using the natural channel design approach that emulates stable rivers and utilizing native materials for physical and ecological enhancement. The hydraulics and the sediment competence and capacity calculations of the proposed river channel indicate that the proposed design will create a more sustainable river system, even with the lateral and vertical constraints imposed. The improved riparian corridor will also help to maintain streambank stability and river function and will provide a more natural visual appearance.

Objective #2: *Reduce flood stage through Saratoga*

Flood stage can be reduced by decreasing the excess sediment deposition, lowering the channel width/depth ratio, and increasing the mean velocity and stream power. The vertical constraints imposed by the utility-line crossings and the presence of bedrock limit the extent of the potential flood-stage reduction. The project will not increase flood stage, but the projected reductions are minimal. A detailed HEC-RAS flood study is recommended for a final design.

Objective #3: *Reduce the sediment deposition through the project reach*

The sediment competence and sediment transport capacity models indicate that the proposed design will significantly reduce the sediment deposition through the project reach.

Objective #4: *Reduce the sediment supply within the project reach*

Reconfiguring the channel morphology and using Toe Wood, J-Hook Vanes, and Cross-Vanes with the construction of a bankfull bench where needed will greatly reduce the existing streambank erosion and associated sediment supply within the project reach.

Objective #5: *Protect private property and public Infrastructure from erosional processes*

The proposed streambank stability work using Toe Wood and the near-bank stress reduction with the use of J-Hook Vanes will protect property and infrastructure from accelerated erosion observed during past flood flows.

Objective #6: *Maintain the integrity and function of bridges*

The use of rock structures and the double W-Weir will reduce bridge pier scour and will improve the sediment transport capacity through the bridge openings.

Objective #7: *Protect river corridor utilities*

Rock vane structures are used at utility crossing locations to reduce bed scour and to add further protection from future floods.

Objective#8: *Protect the hot springs*

The design will not result in excavation into bedrock; thus any potential impacts to the hot springs are avoided. Additional investigations are required for a final design.

Objective #9: *Improve aquatic habitats*

The decreased width/depth ratio and greater depths for the same flows will enhance the instream cover at low flows. Toe wood will also provide exceptional instream and overhead cover as the structure creates undercut banks. Instream cover is also afforded by the use of the J-Hook and Cross-Vane structures. Overall, the aquatic habitat will be enhanced by improving winter and high flow refugia and reestablishing the riparian corridor that provides shading and benefits terrestrial insects.

Objective #10: *Facilitate recreational boating*

The proposed instream vane structures do not create boating hazards as tested on numerous large rivers where recreational boating is prevalent. Also, the Toe Wood is submerged and creates a fast/slow water seam offset from the structure; thus velocity distribution does not carry boats into the structure. Also, the use of the vane structures to slow the currents near the streambanks will also help boating enthusiasts and fly fisherman.

Objective #11: *Enhance the riparian corridor*

The plantings and management of the riparian corridor is part of the long-term stability and function of the river restoration.

Objective #12: *Improve the Pick Ditch diversion*

The present diversion structure that creates backwater and excess sediment deposition leading to high maintenance for the land owner will be replaced with a Cross-Vane structure with a headgate and sediment sluice design. These structures have proved to be efficient with low maintenance by reducing sediment and fish from entering the diversion canal; the structure also provides for safe boating conditions and for sediment transport through the structure with no migration barriers for fish.

7.0 RECOMMENDATIONS

The design team recommends that the geomorphic assessment and conceptual design reports be widely distributed amongst the local constituency to secure additional objectives that may have been over-looked and to provide ample opportunity for land owners and agencies to properly evaluate the proposal. If the conceptual restoration plan is approved, many of the preliminary design components and relations must be validated.

A final restoration design must verify the estimated flood stage reductions (although slight) with a detailed flood-level study. A detailed wetlands map and a riparian corridor management plan are also necessary. A detailed geologic investigation is also recommended to assess the hot springs to ensure that they will not be adversely affected by the restoration proposal. A formal bridge pier analysis (WYDOT)and hydraulic analysis are necessary to determine the present integrity of the bridges. A quantitative assessment of the fish biomass and specific habitat limitations for various age classes and species will help in refining specific habitat enhancement strategies. Also, investigating the minimum required bed cover over the water and sewer pipelines dealing with bed ice potential is recommended to validate maximum channel depths. A complete reference reach survey must also be conducted at the streamgage on the North Platte River at Northgate to validate all design parameters.

Last, to ensure that the proposed restoration will have long-term sustainability, it is recommended that the accelerated sediment supply from the upstream streambank erosion sources be reduced. A master plan to assess and design the upstream reaches for all ownerships is recommended to offset land loss and the high sediment supply and to set priorities for specific future design scenarios.

8.0 SUMMARY

The conceptual design was developed from the multiple project objectives and requests from the local community of Saratoga. In response to these requests, a geomorphic assessment was conducted to address the current conditions of the North Platte River through Saratoga and to identify the causes and consequences of impairment to direct the conceptual restoration plan. The conceptual design addresses the project objectives and provides the initial framework to seek out required funding to implement the restoration.

Additional objectives or requests that may have been overlooked can be incorporated into future planning opportunities. The conceptual design will help direct solutions to additional objectives as the community moves forward to determine how to best coexist with their river.

9.0 LITERATURE CITED

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Rosgen, D.L. (1996). *Applied River Morphology*. Pagosa Springs, CO: Wildland Hydrology.

Rosgen, D.L. (2007). Chapter 11: Rosgen Geomorphic Channel Design. In J. Bernard, J.F. Fripp, & K.R. Robinson (Eds.), *Part 654 Stream Restoration Design National Engineering Handbook* (210-VI-NEH, pp. 11-1–11-76). Washington, D.C.: USDA Natural Resources Conservation Service.

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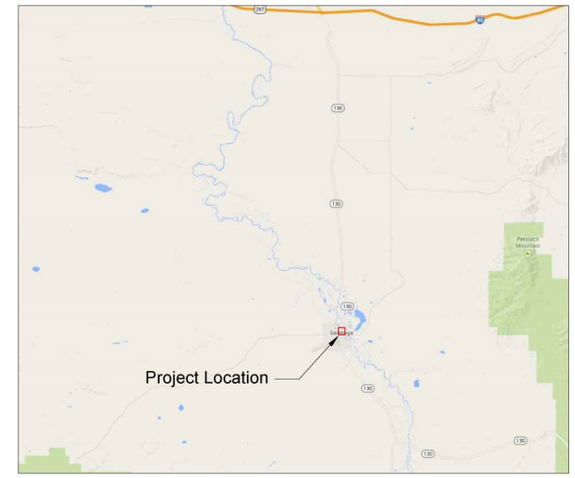
APPENDIX A: CONCEPTUAL DESIGN PLAN SET

Town of Saratoga
North Platte River
Conceptual Design Plan Set

Aug. 2014

Project Number: 212205023



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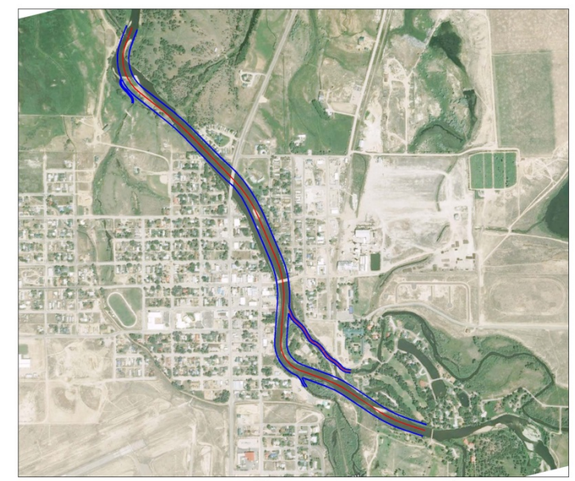

Location Map: NTS

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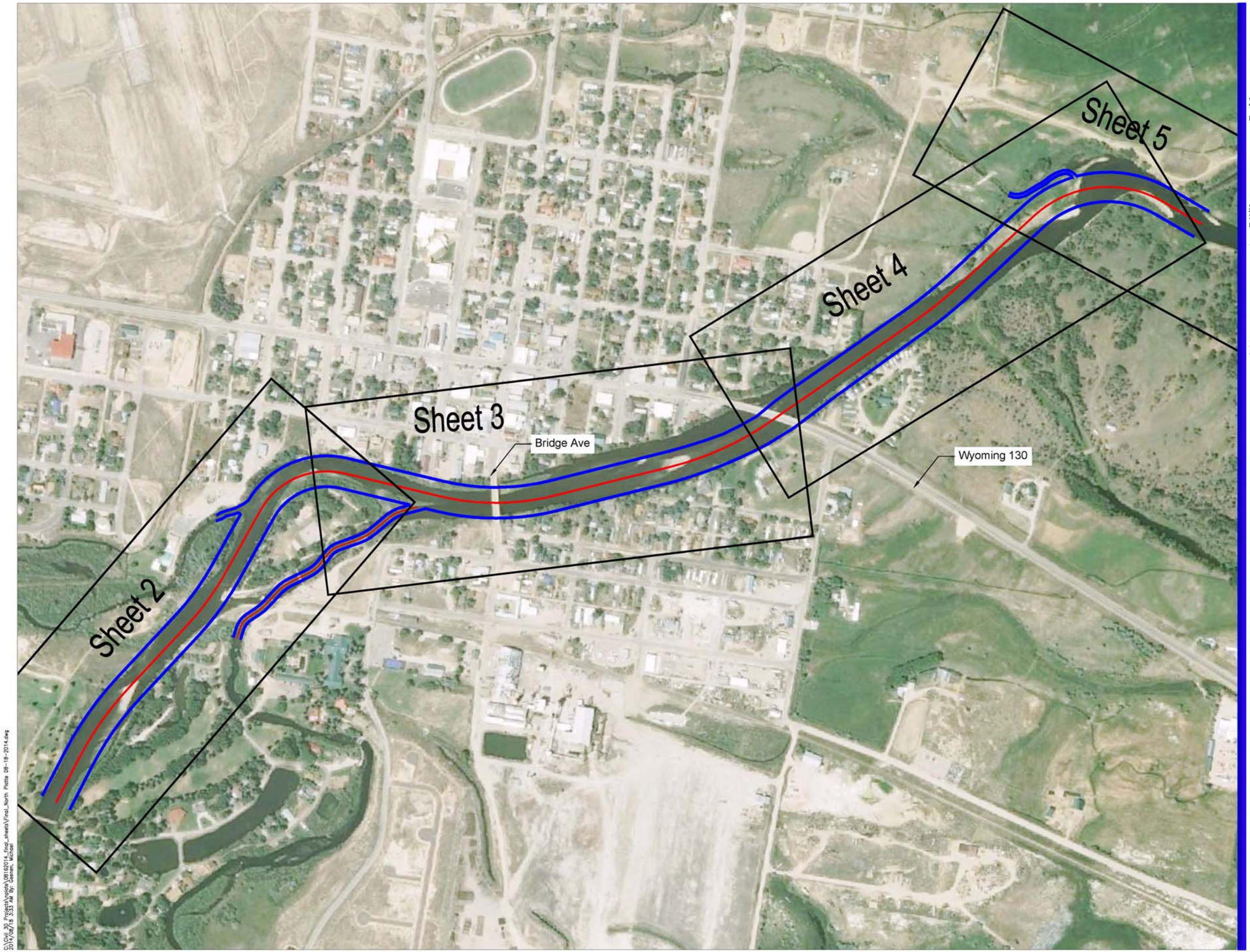

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Legend

Proposed Stream Alignment

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Client/Project
Town of Saratoga

North Plattte River
Stream Restoration Concept Design
Saratoga, WY

Title
Conceptual Design
Plan View

Project No.
212205023

Scale
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Drawing No.

Sheet
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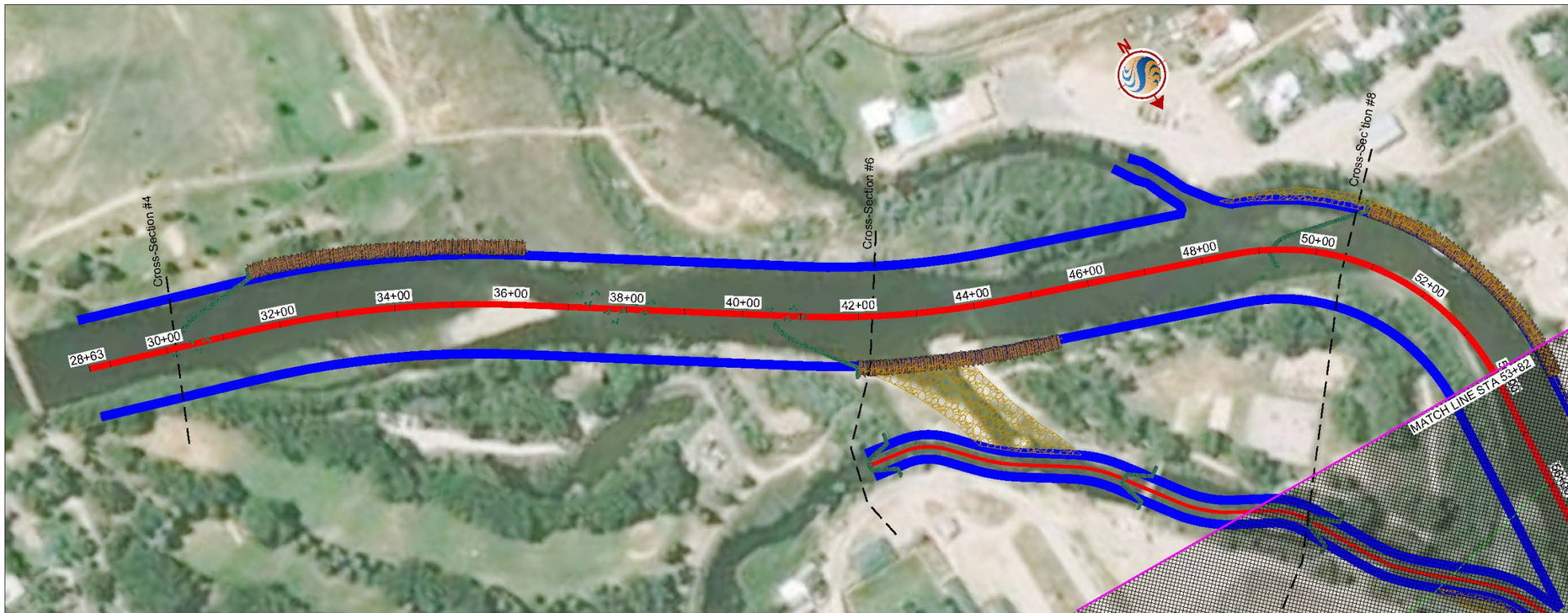

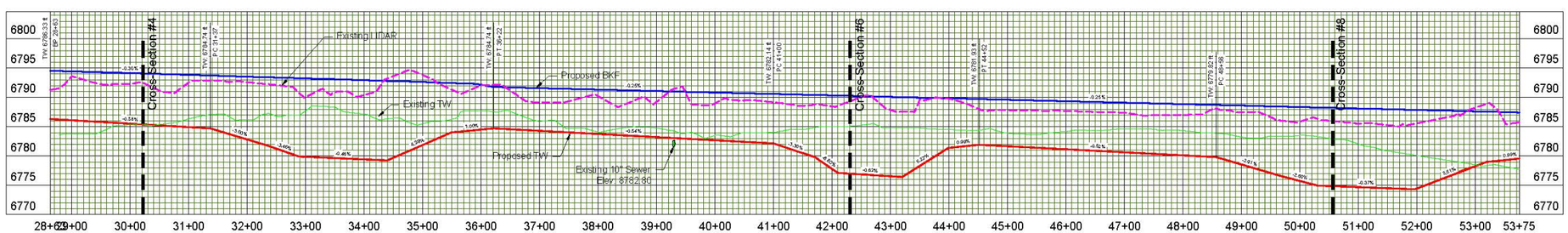

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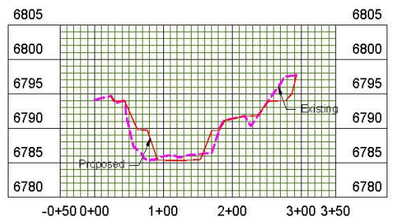

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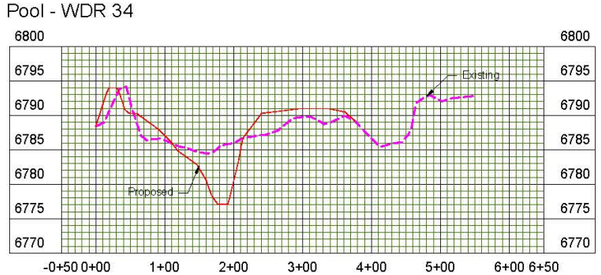

Cross-Section #8
STA: 50+58
Pool - WDR 31

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Legend

- Proposed Stream Alignment
- Rock J-Hook
- Toe Wood
- Bankfull Bench and Fill Areas
- Rock Cross Vane
- Converging Boulder Clusters

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Client/Project
Town of Saratoga

North Plattte River
Stream Restoration Concept Design
Saratoga, WY

Title
Conceptual Design
Plan/Profile/Cross-Section

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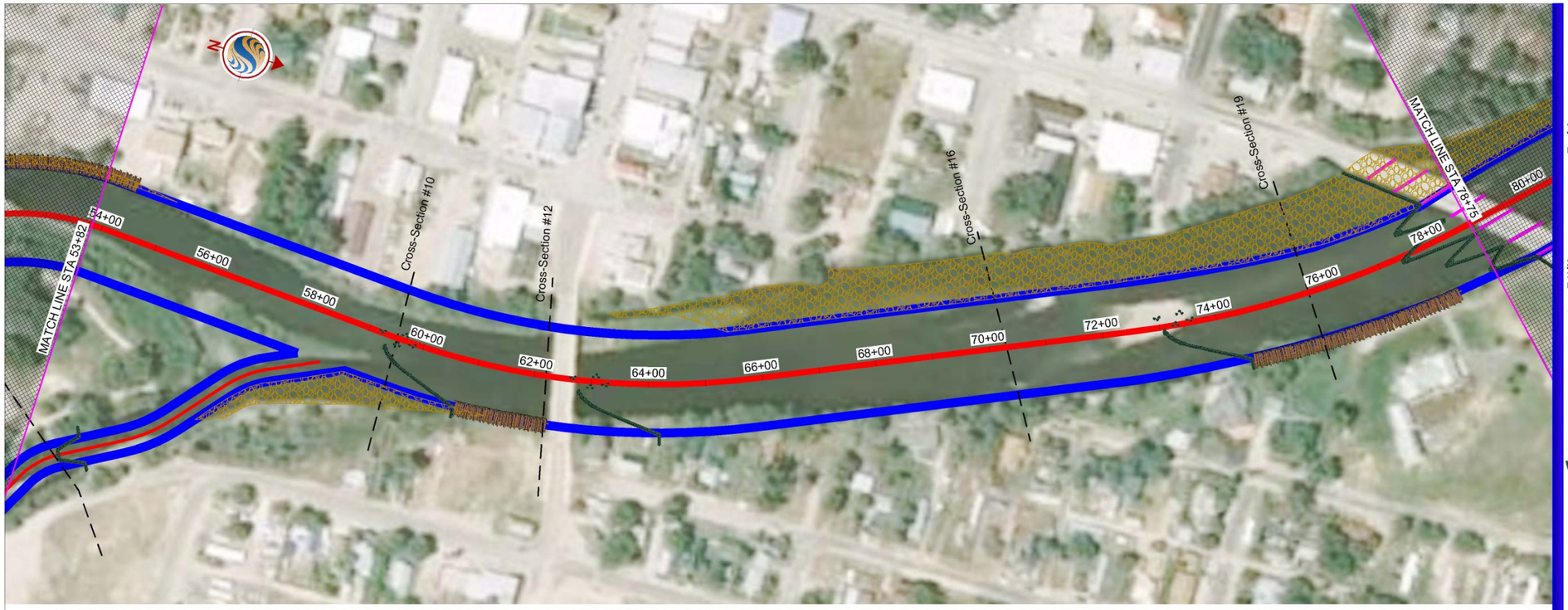

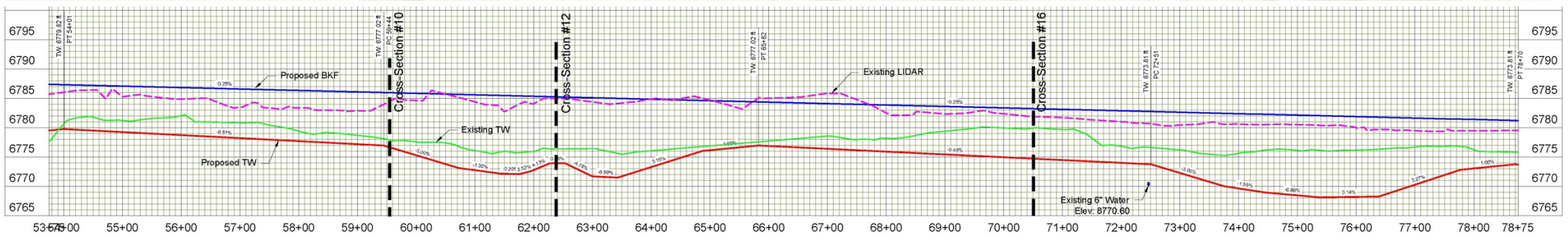

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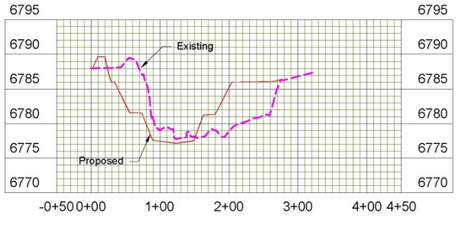

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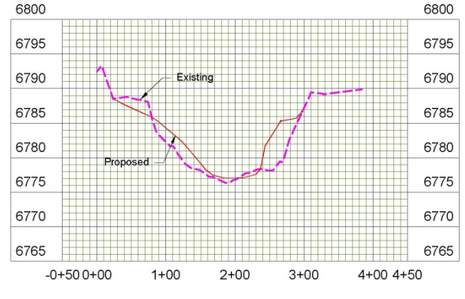

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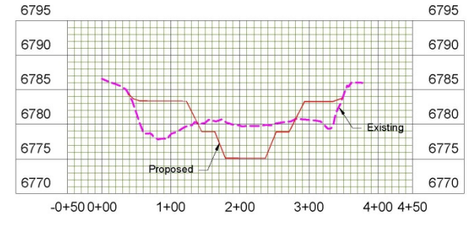

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Legend

- Proposed Stream Alignment
- Rock J-Hook
- Toe Wood
- Bankfull Bench and Fill Areas
- Rock Cross Vane
- Rock W-Weir Structure

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Saratoga, WY

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Sheet 3 of 5
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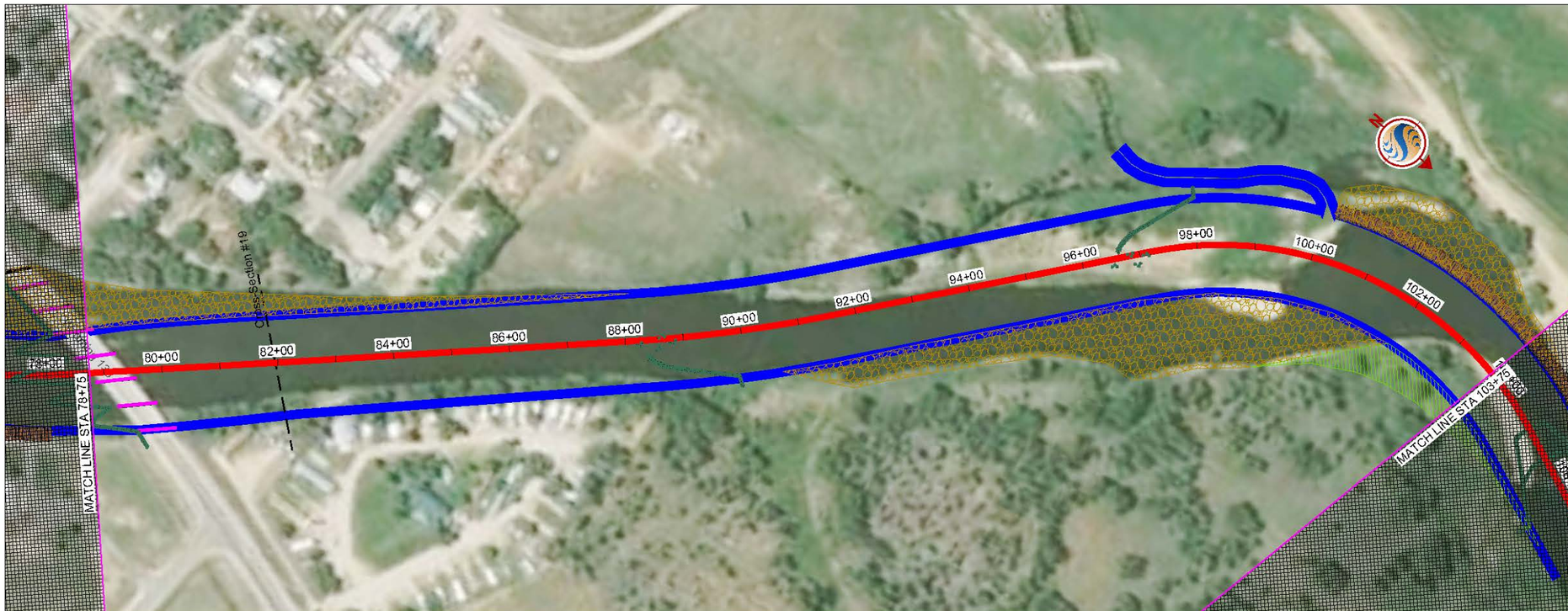

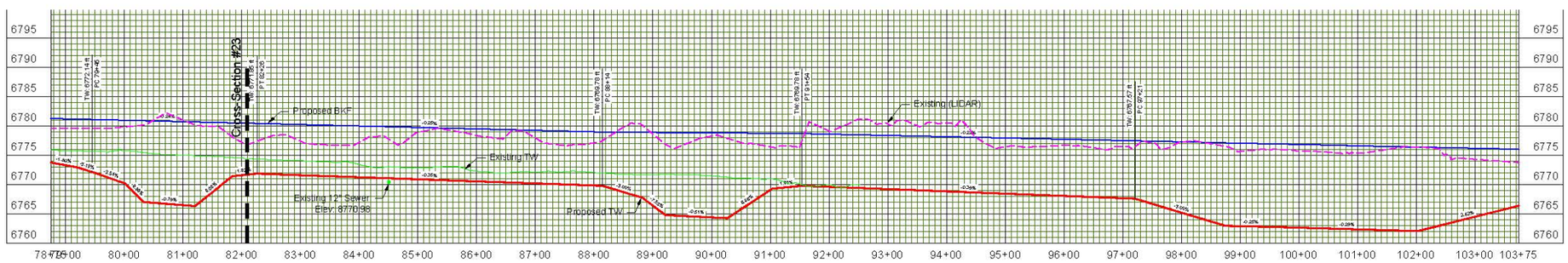

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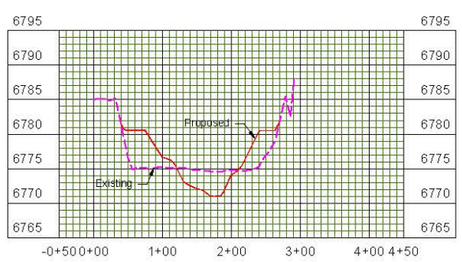

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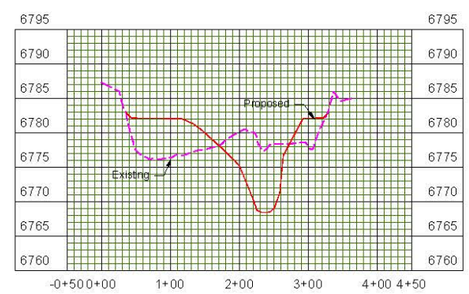

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Legend

- Proposed Stream Alignment
- Rock J-Hook
- Toe Wood
- Bankfull Bench and Fill Areas
- Cut Area Point Bar

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Saratoga, WY

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Project No. 212205023

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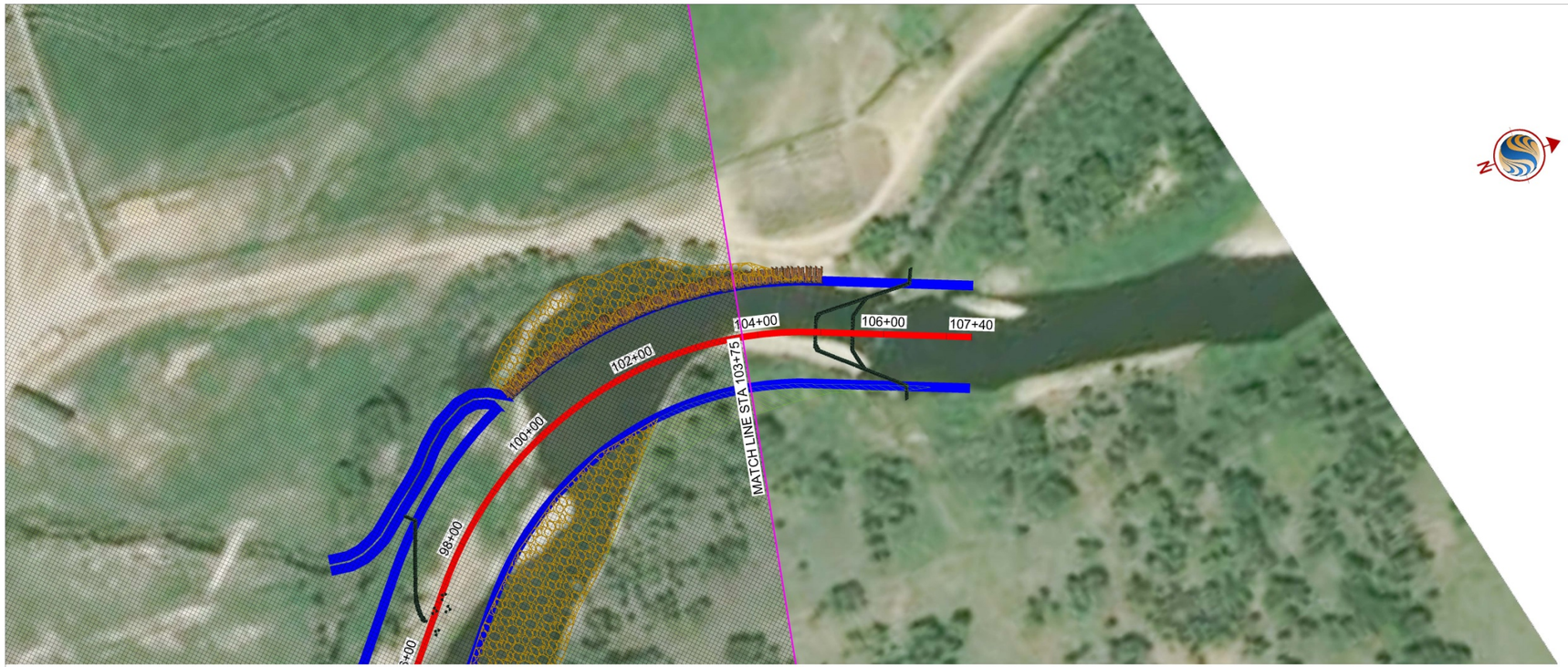

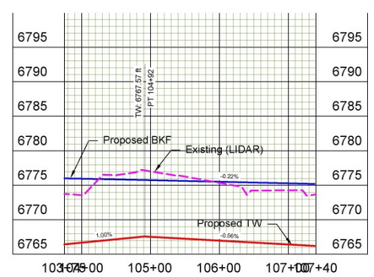

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Legend

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- Double Step Cross Vane
- Toe Wood
- Cut Area Point Bar

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