Geomorphology & River Assessment: North Platte River, Saratoga, Wyoming

Town of Saratoga River Study

Prepared for:
Town of Saratoga

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July 2nd, 2014

Sign-off Sheet

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1.0 PROJECT BACKGROUND

A geomorphic assessment of the North Platte River through the town of Saratoga, Wyoming, was conducted to evaluate existing conditions and inform potential stream restoration. The impetus for this work comes from past and future flooding impacts, poor aquatic habitat, sedimentation problems, land loss associated with accelerated streambank erosion, and problems with both irrigation diversions and river crossings. The assessment was conducted to examine the existing conditions; the nature, extent, and consequences of river impairment; and the loss of physical and biological functions. The existing condition is compared to a reference condition to determine the degree of impairment and the departure from the potential geomorphic stable state of the river. This assessment provides direction to guide potential river restoration activities in the future. Such activities would be designed to offset the impaired conditions identified in this report, and to serve as a demonstration for future master planning efforts for other reaches of the North Platte River with similar impacts.

2.0 PROJECT LOCATION & LAND USE HISTORY

The city of Saratoga is located on the North Platte River in south-central Wyoming. **Figure 1** depicts the vicinity map of the assessment reach that is located upstream and downstream of Saratoga and spans approximately 2.0 miles.

The North Platte River through Saratoga has a long history of disturbance affecting the dimensions, pattern, profile, and overall stability and biological functions of the river. Log and railroad tie drives occurred from the 1860s to the early 1930s where thousands of logs and ties per year were floated down the North Platte River to mills and tie landings as far as Ft. Steele (**Figure 2**). Structures to direct flows away from the streambanks were installed along the river as shown in the photograph in **Figure 2**; some bank structures are still evident as observed upstream during the assessment.

The North Platte River also has many bridges that have caused backwater conditions at higher flows resulting in excess deposition, flood risk, lateral erosion, and land loss. Cross-channel "push-up" dams for irrigation diversions have also increased the width/depth ratio of the river channel leading to increased sediment deposition, high maintenance, and diminished aquatic habitat. The Pick Ditch diversion at the lower end of the project reach has caused excess deposition, streambank erosion, and backwater resulting in headward sediment deposition and high maintenance with the dam and diversion canal. Flow diversions for agricultural purposes during base flows have also adversely impacted the river temperature and holding cover for fish. Imported water due to the Cheyenne project has increased streamflows to the North Platte River that may help offset local depletions. An evaluation of the existing flow-duration curves from the streamgage station will help ascertain potential impacts.

Additionally, riparian vegetation communities of cottonwood and willow were converted to grass/forb communities throughout various locations of the North Platte River, leading to accelerated streambank erosion, land loss, and increased sediment supply. In 1950, channel

dredging attempted to remove in-channel bars and islands as evident in the photograph in **Figure 3** from around 1948; aerial photographs in 1958 showed the bars starting to rebuild at the same reach eight years following dredging. The aerial photographs at this reach also indicated a very high channel width between the Bridge Street and First Street bridges. The extensive bars were reformed due to the river's high width/depth ratio and the bridge influence; such dredging is a temporary solution at best, and diminishes fish habitat and river stability.

The channel pattern of the North Platte River adjusted between 1994 (**Figure 4**) and 2009 (**Figure 5**) as a by-pass channel was cut through the existing island to divert streamflows to the right channel (NE side) of Veterans Island. This by-pass diversion may have been constructed to reduce the streamflow convergence against the mainstem, downstream left bank where rock rip-rap had been placed. The channel pattern is much straighter through the developed portions of Saratoga than that observed above and below the town. This may indicate channelization and straightening activities in the past.

The North Platte River through Saratoga has also had a history of major floods and associated impacts, which are not uncommon for communities historically established along river corridors and floodplains. According to the Wyoming Department of Water Resources at the streamgage in downtown Saratoga, since the major flood of 1917, the largest flood of record was in 2011, when on June 9th, flows of16,922 cubic feet per second (cfs) (flood stage 10.42 ft) occurred as shown in **Figure 6**. Recently, on May 28, 2014, a major high magnitude flood of 14,611 cfs (flood stage 10.14 ft) occurred.

Last, the North Platte River has many constraints, including the natural hot springs that occur along the river corridor in Saratoga, which brought Indian tribes to the region to experience the "place of magic waters". The hot springs have had historic value since the late 1800s for their healing values as described by the state Geologist of Wyoming (Bartlett, 1926), where "hopeless rheumatics have been cured in two to six weeks…victims of liquor and tobacco have been entirely cured…sufferers from stomach and intestinal disease have been sent away happy at the first freedom of pain, completely cured." Subsequent economic developments and recreation have bolstered the local economy due to the presence of these high mineral, low sulphur hot springs. Impacts to these hot springs occurred several years ago when in-channel excavation introduced surface river water to the ground water, temporarily reducing the water temperature of the hot springs. This was mitigated by "resealing" the disturbance with concrete.

Additional constraints to the river include the numerous utility corridor crossings of sewer and water lines in addition to the existing and proposed bridge crossings as indicated in **Figure 7** (see ***APPENDIX I*** for additional information supplied by the town of Saratoga and surveyed cross-sections related to the constraints in **Figure 7**).

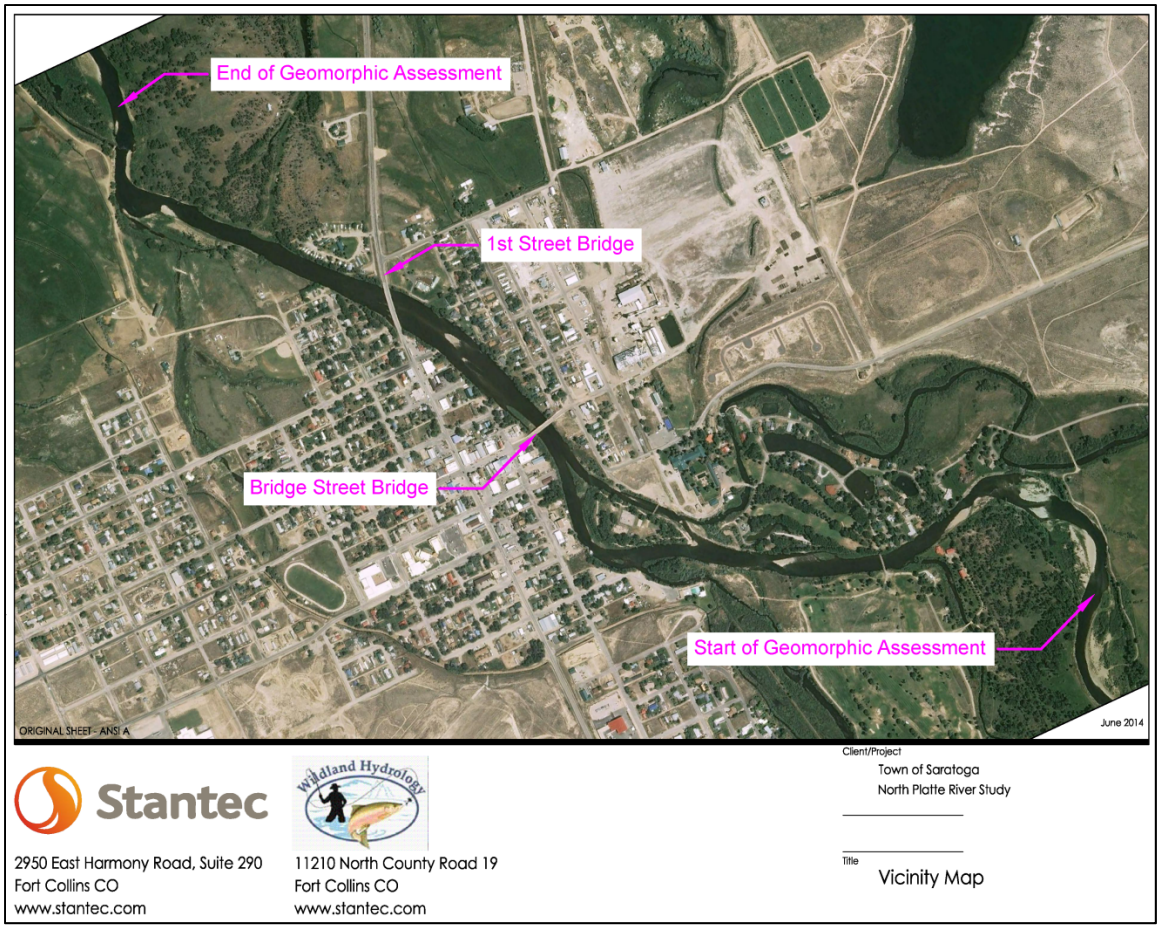


Figure 1. Vicinity map of the assessment reach on the North Platte River through Saratoga.

Figure 2. Historical photograph around 1910 of logs floating down the North Platte River and a bank structure to direct the flow away from the streambank.

Upper North Platte River thru Saratoga between 1943—when Bridge St. Bridge (center) was re-built—and 1950 when First St. (Hgw. 130) Bridge built. Island between bridges was removed in 1950 to prevent debris from gathering on it and washing against new bridge, causing damage.—
Photo by Bob Martin, courtesy of Dick Perue of Historical Reproductions by Perue. circa 1948.

Figure 3. Historical photograph around 1948 showing the island between the Bridge Street and the First Street Bridges.

Figure 4. Aerial photograph in 1994 of the North Platte River through Saratoga showing bar development between the bridges.

Figure 5. Aerial photograph in 2009 showing persisting bar development between the two bridges on the North Platte River.

Figure 6. The flood of 2011 near Saratoga of 16,922 cfs – 3.3 times greater than the normal, high flow discharge.

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 7. Locations of utilities and encroachment constraints along the North Platte River (see ***APPENDIX I*** for the indicated exhibits as supplied by the Town of Saratoga and for associated surveyed cross-sections).

3.0 GEOLOGY

The Saratoga Basin between the Precambrian masses of the Medicine Bow Range to the east and the Sierra Madre to the southwest is associated with a series of anticlines and faults that separate the north and south basins. The US Geological Survey summarized the geology of the area and described the Miller Hill Plateau as an erosional remnant of tuffaceous sedimentary rocks of sandstone and limestone of tertiary age extending north from the Sierra Madre west of Saratoga. Three anticlines and associated faults (Ft. Steele, St. Marys, and Pass Creek) separate the Saratoga Basin to the north. The Saratoga Basin is separated from the North Park Basin to the south by the Independence mountain fault. Precambrian rocks have thrust southward over younger Paleocene rocks along the east-trending fault that dips northward (Stevens and Bergin, 1955). The hot springs are related to a deep ground water source influenced by faults that trend in a southerly direction also observed in central Colorado.

4.0 STREAMFLOWS

The State of Wyoming Water Resources Department has been measuring the streamflows of the North Platte River in Saratoga since 1992 and, prior to that, the US Geological Survey measured the streamflows from 1905 to 1970. The streamflows are associated with a drainage area of 2,840 square miles (mi^2). **Table 1** summarizes the return period flows versus peak streamflow discharges based on the exceedance probability, and **Figure 8a** depicts the flood-frequency curve for the North Platte River at Saratoga using data from 1992 to 2014. The field-determined bankfull discharge is associated with a flow of 5,200 cfs, which corresponds to approximately a 1.55 year return period. **Figure 8b** illustrates the hydraulic geometry relations from streamflow measurements at the gage station representing channel dimensions and velocity versus discharge. **Figure 9** depicts a flow-duration curve for the North Platte River, which is used in the sediment transport capacity evaluation.

Table 1. Summary of the flood frequency relations for the North Platte River at Saratoga.

Return Period (years)	Peak Flow (cfs)
1.01	1,218
1.25	3,832
1.5	4,880
2.0	7,050
5.0	11,383
10	15,574
25	16,617
50	20,989
100	23,768

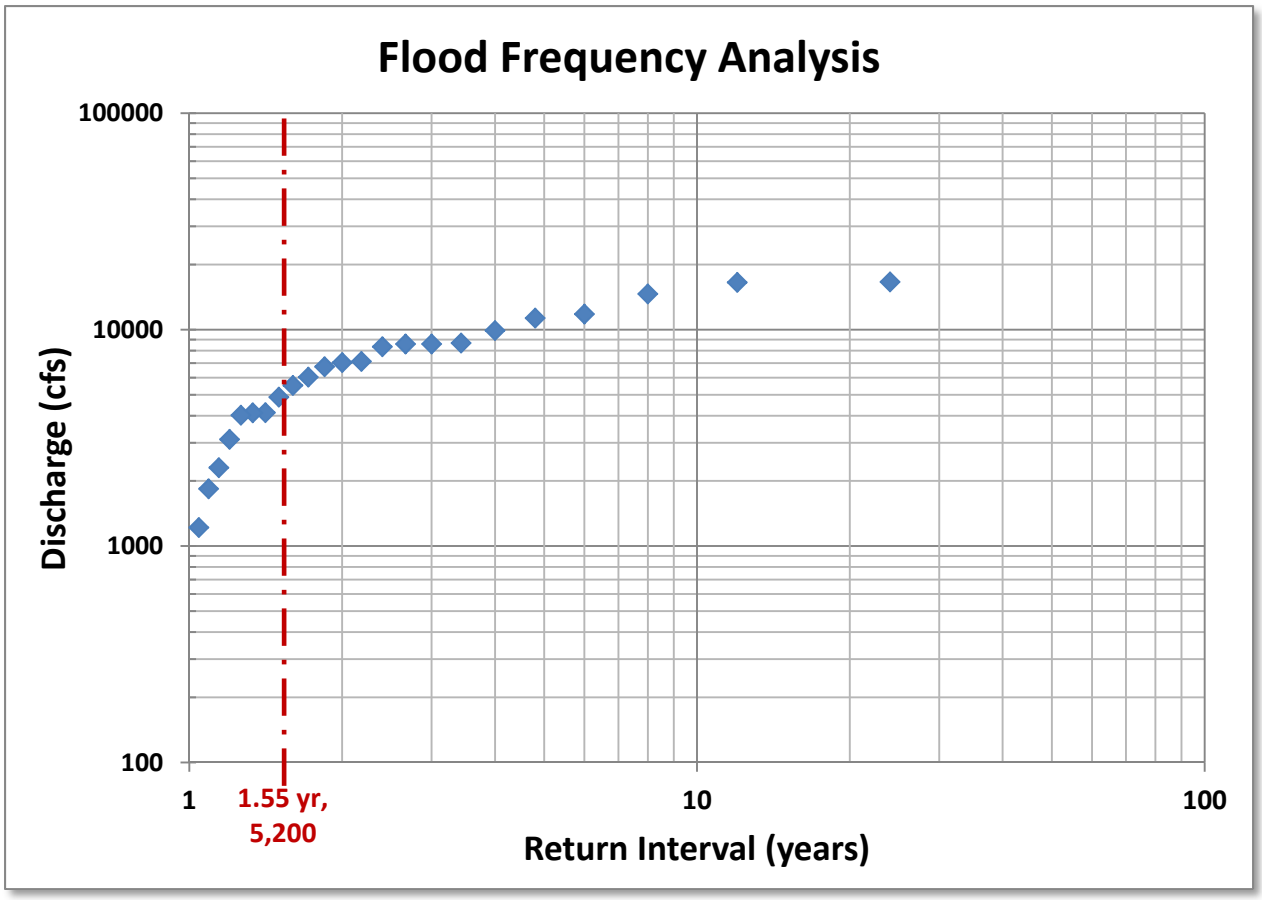
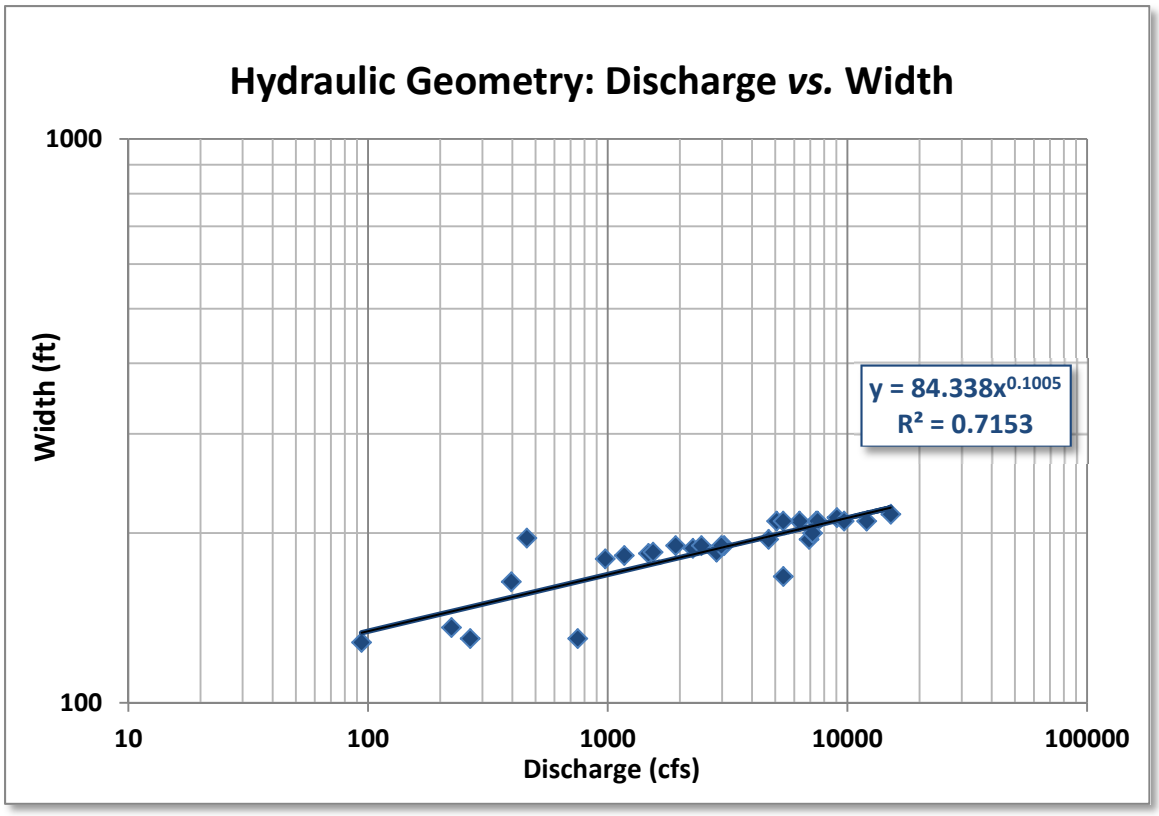


Figure 8a. The flood-frequency curve for the North Platte River at Saratoga.



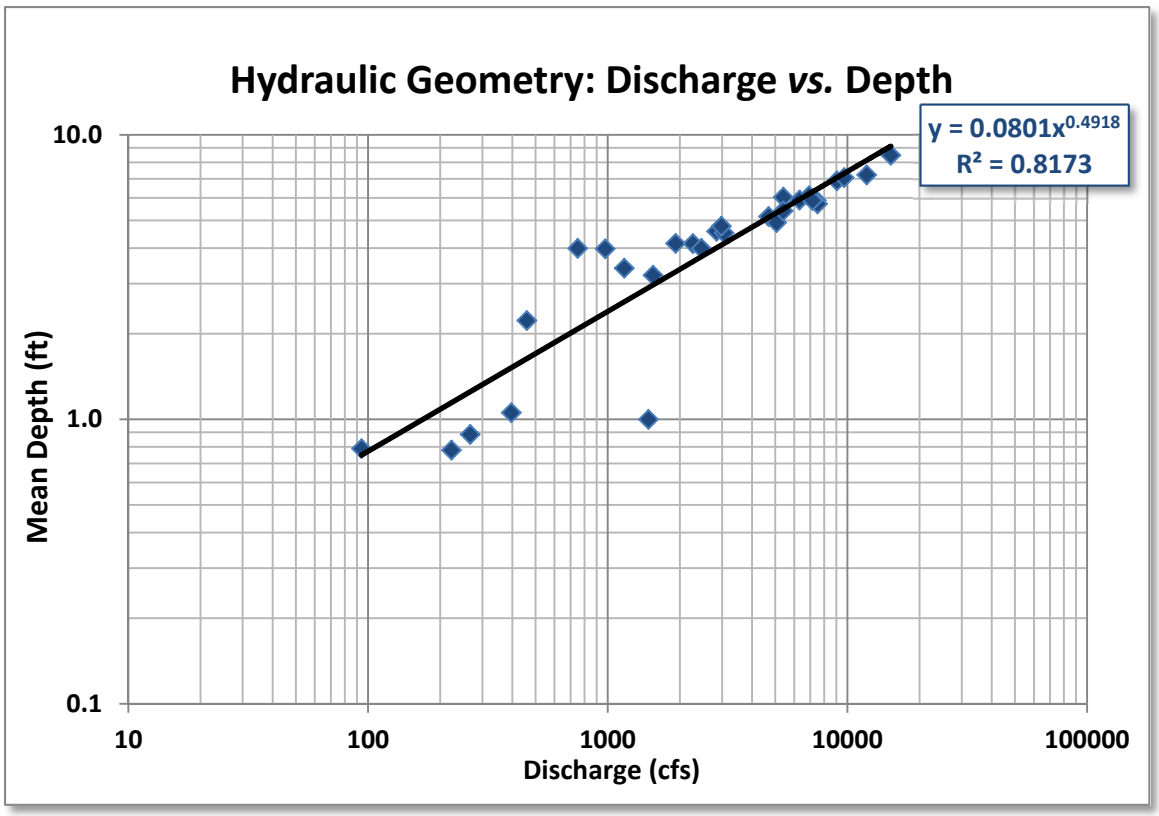
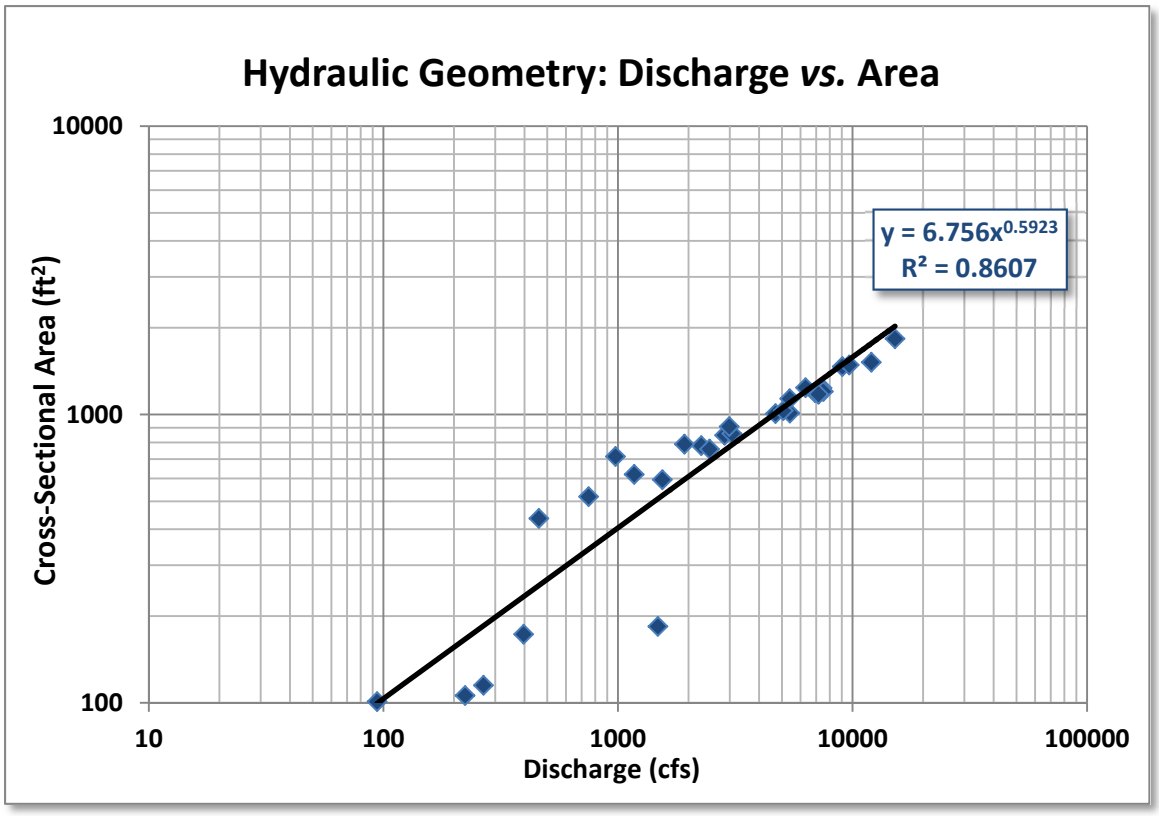


Figure 8b. Hydraulic geometry relations of channel dimensions and velocity *vs.* discharge developed from streamflow measurements at the gage station (page 1 of 2).



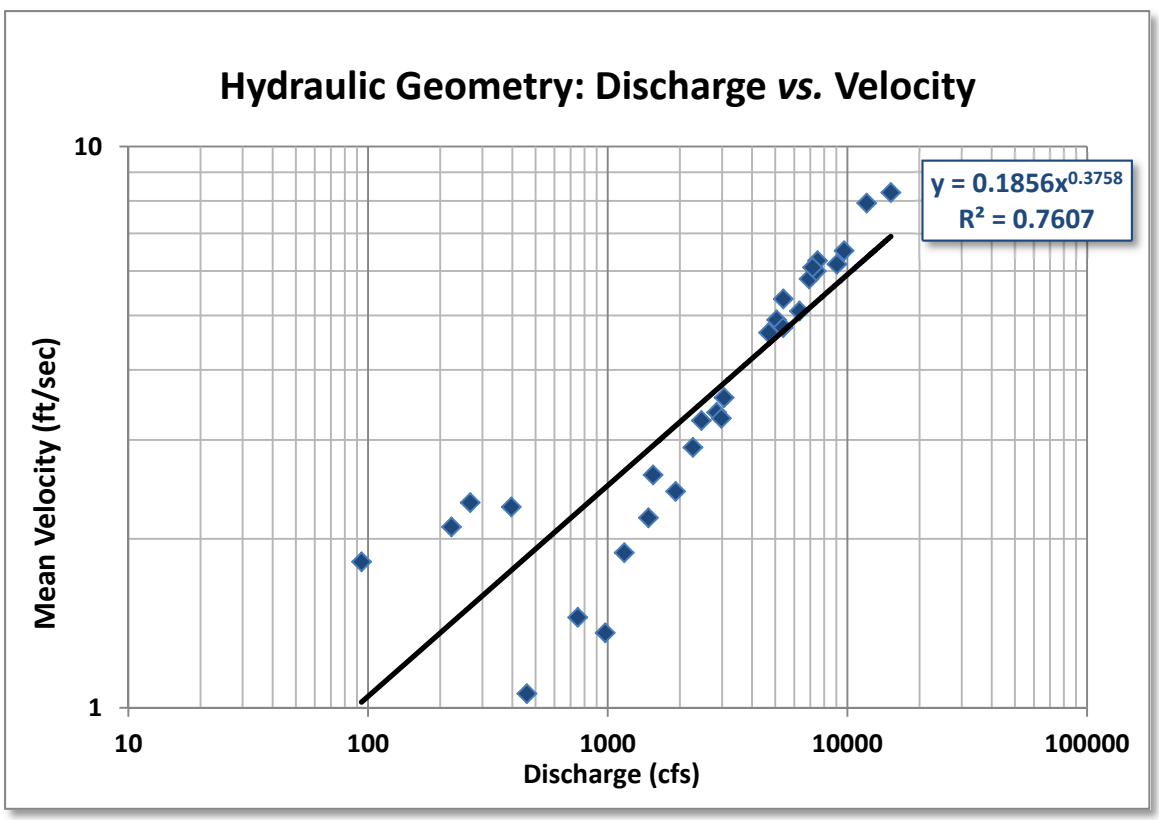


Figure 8b, continued. Hydraulic geometry relations of channel dimensions and velocity *vs.* discharge developed from streamflow measurements at the gage station (page 2 of 2).

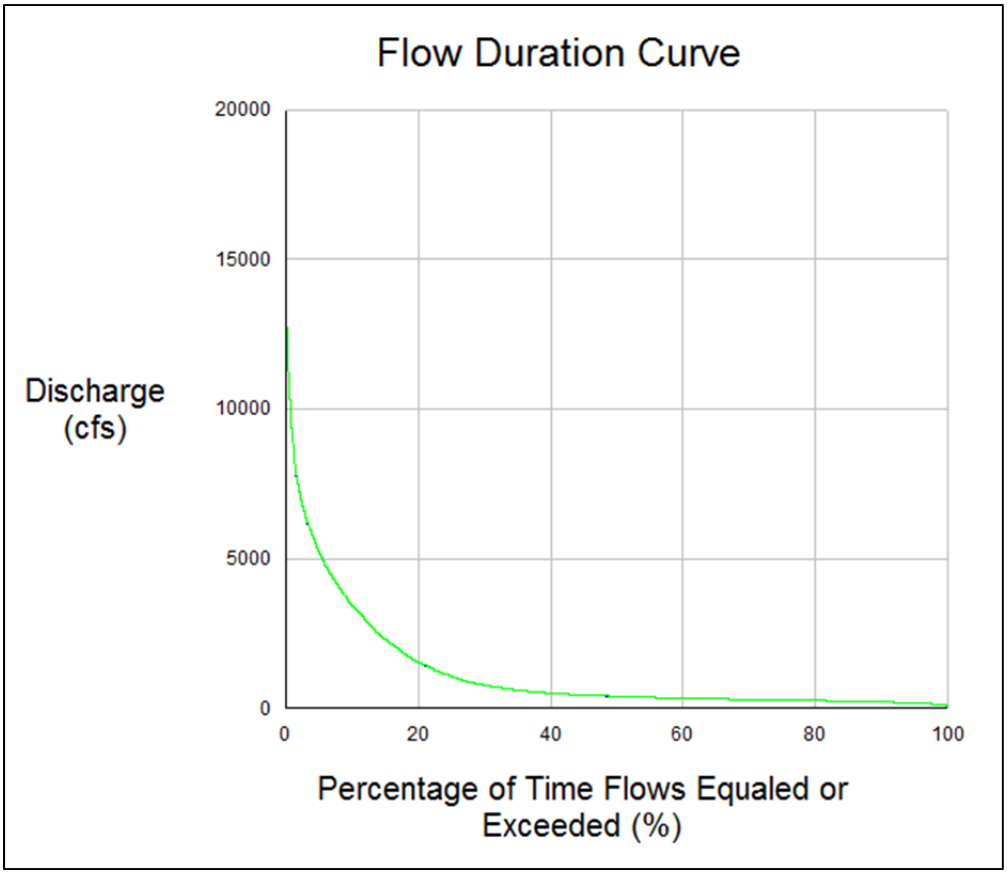


Figure 9. The flow-duration curve for the North Platte River at Saratoga (graph from RIVERMorph™).

5.0 GEOMORPHIC ASSESSMENT

The landform of the North Platte River is associated with an unconfined alluvial valley; ***APPENDIX II*** summarizes the fluvial landscape types, including the unconfined, alluvial valley (*U-AL-FD*). The river is bounded by high pediment surfaces of gravel that overlay sandstone and limestone. A relatively high sand supply is added to the river due to lateral accretion against these high pediment terraces. Holocene or river terraces are also present that are associated with stratified deposits of coarse cobble to fine sand river alluvium.

The North Platte River is a meandering, single-thread, cobble-bed channel with floodplain connectivity on slopes less than 0.022 feet/feet and a width/depth ratio greater than 12.0, which corresponds to a C3 stream type (see ***APPENDIX III*** for a summary of stream classification from Rosgen, 1994, 1996). The bedrock outcrops as evident within the bed of the North Platte River through Saratoga may be responsible for a previous channel pattern change as observed in the aerial photograph shown in **Figure 10**. The upstream pattern of abandoned meander scrolls, multiple-thread channels (D3, D4, and DA4 stream types, ***APPENDIX III***), and associated avulsion channels and oxbows are much different than the pattern of the downstream reach; Downstream of town, the previous river pattern is similar to the above Saratoga reach as depicted in **Figure 10**.

Figure 10. An aerial photograph from 1999 of the North Platte River showing previous, multi-thread, D3 stream types in addition to avulsion patterns and oxbow channels upstream and downstream of the straightened reach through Saratoga.

5.1 STREAM MORPHOLOGY

The North Platte River through the town of Saratoga was determined to be a C3 stream type with a cobble-bed channel, with an average slope of 0.00218 feet/feet and an unusually high width/depth ratio range from 63 to 106, with an average of 80. Typical bed features of C3 stream types include riffles, runs, pools, and glides. **Table 2** shows the stream type summary of a typical riffle reach of the North Platte River.

Table 2. Stream classification and a summary of the morphological variables of the North Platte River through Saratoga associated with a C3 stream type.

Stream:	**North Platte, Existing Condition, Riffle XS-19 75+87**				
Basin:	**North Platte**	Drainage Area:	acres	**2,840**	mi^2
Location:	**Saratoga, Wyoming**				
Twp.&Rge:		Sec.&Qtr.:			
Cross-Section Monuments (Lat./Long.):				Date:	**06/19/14**
Observers:	**BR & MG**			Valley Type:	**U-AL-FD**

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**289.82**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**4.15**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**1201.97**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**69.84**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**6.27**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**6,300**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**21.74**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**128**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.00218**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.17**	

Stream Type **C3** (See ***APPENDIX II***)

5.1.1 Stream Cross-Sections

A total of 23 cross-sections were surveyed to obtain bankfull channel dimensions for riffles, runs, pools, and glides; two of the cross-sections were taken upstream and downstream of the First Street bridge. **Table 3** summarizes the bankfull dimensions of channel width, mean depth, cross-sectional area, width/depth ratio, and maximum depth; the data shows consistent high width/depth ratios that present problems for sediment transport and aquatic habitat. **Figure 11** depicts the channel stationing and cross-section locations. **Figure 12** depicts a typical, riffle cross-section associated with a high width/depth ratio. ***APPENDIX IV*** includes the cross-section graphs for all bed features (graphs from RIVERMorph™).

Table 3. Summary of the bankfull cross-section dimensions for all bed features.

RIFFLE Cross-Sections	Bankfull Width	Mean Depth	Cross-Sectional Area	Width/ Depth	Maximum Depth
XS-3 11+99	372.70	3.51	1306.8	106.2	6.76
XS-7 47+80	272.20	4.27	1160.9	63.7	6.98
XS-8 50+58	307.00	3.69	1132.2	83.2	5.92
XS-17 72+91	296.50	3.63	1075.3	81.7	6.71
XS-18 74+03	290.40	3.71	1078.2	78.3	7.15
XS-19 75+87	**289.80**	**4.15**	**1202.0**	**69.8**	**6.27**
XS-20 77+15	292.10	3.75	1094.1	77.9	4.95

RUN Cross-Sections	Bankfull Width	Mean Depth	Cross-Sectional Area	Width/ Depth	Maximum Depth
XS-9 56+40	347.6	3.24	1125.8	107.3	7.78
XS-23 82+08	225.6	4.87	1099.4	46.3	5.67

POOL Cross-Sections	Bankfull Width	Mean Depth	Cross-Sectional Area	Width/ Depth	Maximum Depth
XS-4 30+21	186.30	4.54	846.30	41.0	7.140
XS-5 40+26	417.50	3.86	1612.20	108.2	8.410
XS-10 59+67	192.10	5.86	1125.70	32.8	7.720
XS-11 62+38	196.70	5.09	1002.00	38.7	7.760
XS-12 64+81	222.50	4.98	1108.20	44.7	8.680
XS-13 66+53	193.50	5.63	1088.80	34.4	8.140
XS-14 67+55	268.00	4.71	1262.90	56.9	7.200
XS-15 66+88	290.70	3.86	1122.50	75.3	5.530

GLIDE Cross-Sections	Bankfull Width	Mean Depth	Cross-Sectional Area	Width/ Depth	Maximum Depth
XS-6 42+31	386.1	2.79	1077.5	138.38	5.39
XS-16 70+51	309.5	3.84	1187.3	80.59	5.98

BRIDGE Cross-Sections	Bankfull Width	Mean Depth	Cross-Sectional Area	Width/ Depth	Maximum Depth
XS-21 78+60	382.8	4.81	1840.2	79.58	7.01
XS-22 79+33	408.4	4.59	1874.4	88.97	6.65

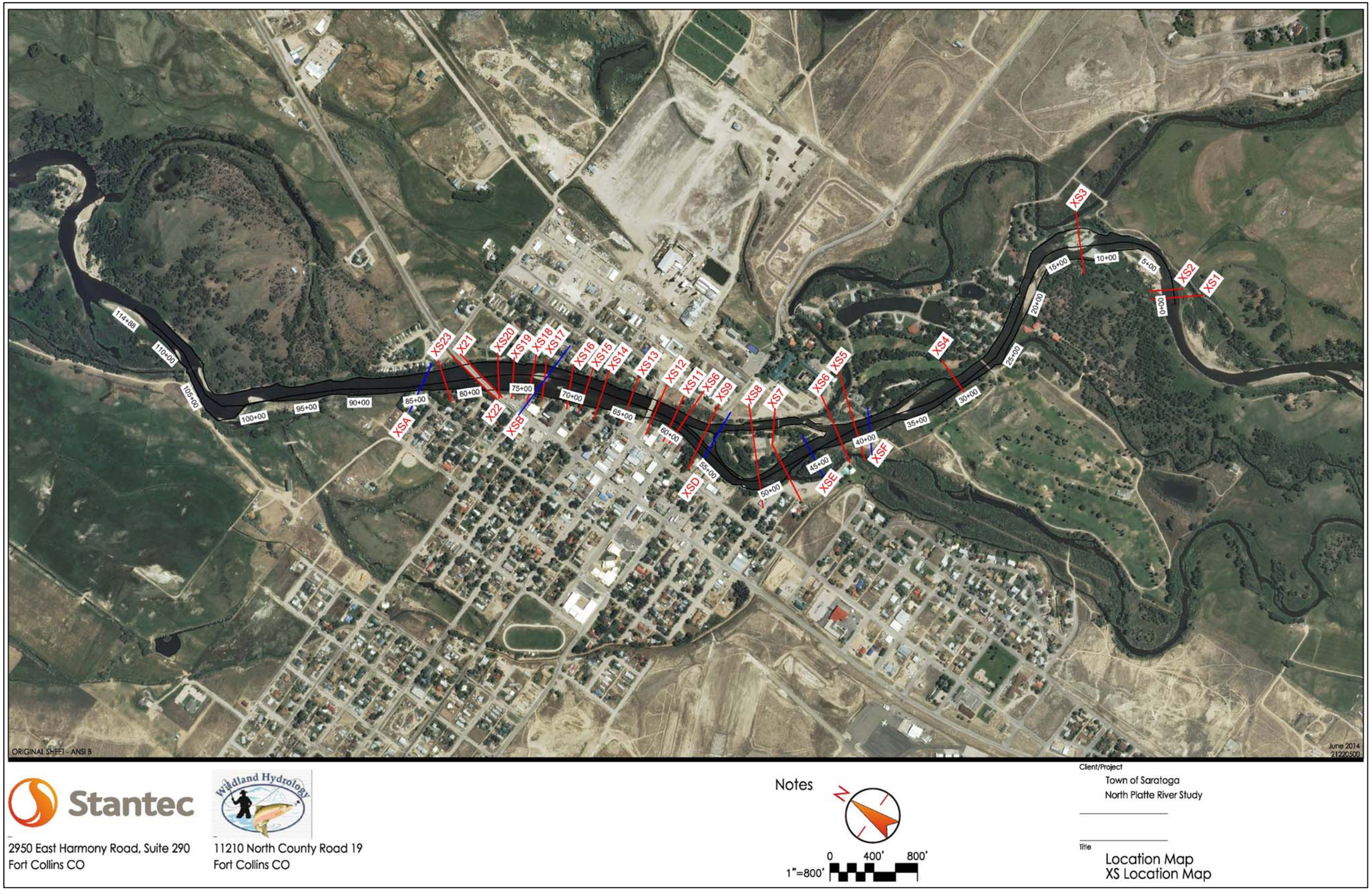


Figure 11. Channel stationing and cross-section locations for the geomorphic assessment on the North Platte River through Saratoga.

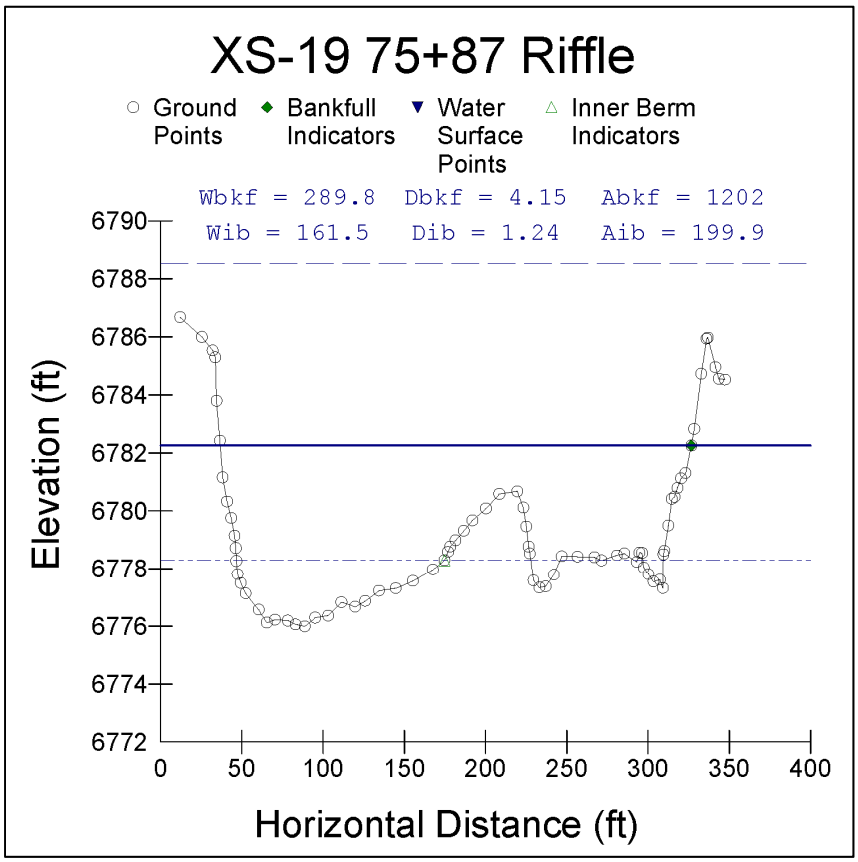


Figure 12. A typical riffle cross-section on the North Platte River through Saratoga (RIVERMorph™).

5.1.2 Longitudinal Profile

Figure 13 illustrates the longitudinal profile measured through the cross-section locations summarized in **Table 3** and depicted in ***APPENDIX IV***. The average water surface slope for the reach is 0.00218 feet/feet (0.22 %). Close agreement between the water surface slope and bankfull elevation slopes is apparent in **Figure 13**. The longitudinal profile is also used to obtain ratios of existing maximum depths and facet slopes of the various bed features.

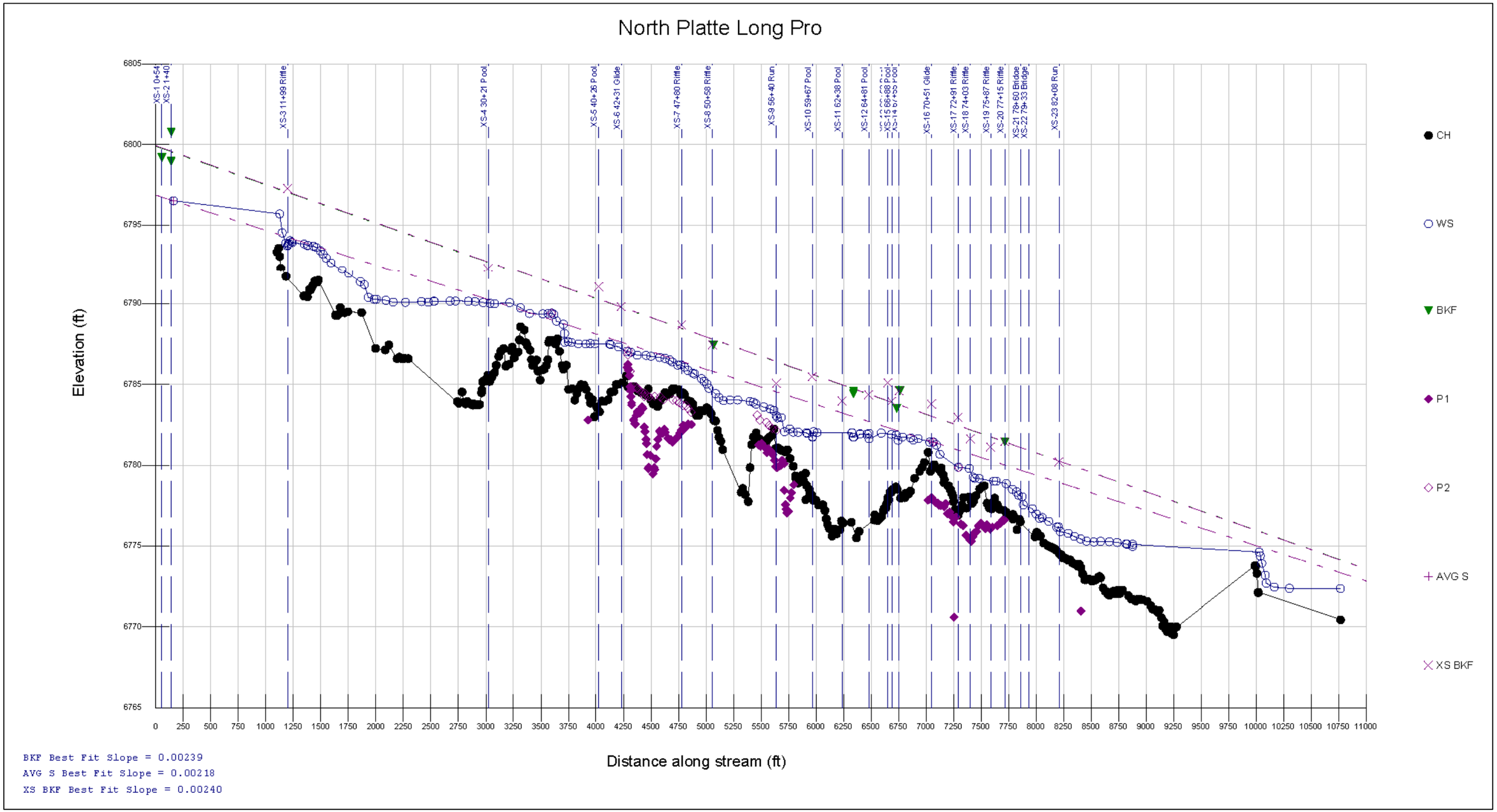


Figure 13. The longitudinal profile for the North Platte River through Saratoga indicating cross-section locations and channel slopes (RIVERMorph™).

5.1.3 Summary of Stream Morphology

The river morphology and dimensionless ratios representing the dimensions, pattern, and profile of all the bed features are summarized in **Table 4**. In later sections this summary data of the existing condition reach is compared to the stable, reference reach data. Initially, it is evident that maximum bankfull depth ratios are very low for the riffle and pool data. The effects of the shallow depths are evaluated in the sediment transport analysis and fish habitat interpretations.

Table 4(a). Summary of the stream morphology and dimensionless ratios from the cross-sections and longitudinal profiles for all bed features (page 1 of 2).

Stream: **North Platte River through Saratoga** Location: **Existing Condition**

Observers: **BR & MG** Date: **06/19/14** Valley Type: **U-AL-FD** Stream Type: **C3**

River Reach Dimension Summary Data…..1

	Riffle Dimensions*, **, ***	Mean	Min	Max		Riffle Dimensions & Dimensionless Ratios****	Mean	Min	Max
Riffle Dimensions*, **, ***	Riffle Width (W_{bkf})	305	272	373	ft	Riffle Cross-Sectional Area (A_{bkf}) (ft^2)	1173.74	1075.30	1306.79
	Mean Riffle Depth (d_{bkf})	3.87	3.51	4.27	ft	Riffle Width/Depth Ratio (W_{bkf} / d_{bkf})	79.59	63.74	106.18
	Maximum Riffle Depth (d_{max})	6.47	4.95	7.15	ft	Max Riffle Depth to Mean Riffle Depth (d_{max} / d_{bkf})	1.681	1.320	1.927
	Width of Flood-Prone Area (W_{fpa})	1984	324	6300	ft	Entrenchment Ratio (W_{fpa} / W_{bkf})	6.771	1.109	21.738
	Riffle Inner Berm Width (W_{ib})	174	87.2	239	ft	Riffle Inner Berm Width to Riffle Width (W_{ib} / W_{bkf})	0.580	0.294	0.860
	Riffle Inner Berm Depth (d_{ib})	1.35	0.86	1.69	ft	Riffle Inner Berm Depth to Mean Depth (d_{ib} / d_{bkf})	0.352	0.238	0.480
	Riffle Inner Berm Area (A_{ib})	238	75.4	366	ft^2	Riffle Inner Berm Area to Riffle Area (A_{ib} / A_{bkf})	0.201	0.070	0.282
	Riffle Inner Berm W/D Ratio (W_{ib} / d_{ib})	131	72.2	201					

	Pool Dimensions*, **, ***	Mean	Min	Max		Pool Dimensions & Dimensionless Ratios****	Mean	Min	Max
Pool Dimensions*, **, ***	Pool Width (W_{bkfp})	246	186	418	ft	Pool Width to Riffle Width (W_{bkfp} / W_{bkf})	0.816	0.618	1.385
	Mean Pool Depth (d_{bkfp})	4.82	3.86	5.86	ft	Mean Pool Depth to Mean Riffle Depth (d_{bkfp} / d_{bkf})	1.303	1.043	1.584
	Pool Cross-Sectional Area (A_{bkfp})	1146	846	1612	ft	Pool Area to Riffle Area (A_{bkfp} / A_{bkf})	1.039	0.767	1.461
	Maximum Pool Depth (d_{maxp})	7.57	5.53	8.68	ft	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})	2.046	1.495	2.346
	Pool Inner Berm Width (W_{ibp})	182	135	249	ft	Pool Inner Berm Width to Pool Width (W_{ibp} / W_{bkfp})	0.752	0.546	0.931
	Pool Inner Berm Depth (d_{ibp})	2.51	1.50	4.00	ft	Pool Inner Berm Depth to Pool Depth (d_{ibp} / d_{bkfp})	0.528	0.299	0.881
	Pool Inner Berm Area (A_{ibp})	427	242	541	ft^2	Pool Inner Berm Area to Pool Area (A_{ibp} / A_{bkfp})	0.387	0.215	0.639
	Point Bar Slope (S_{pb})	0.008	0.040	0.110	ft/ft	Pool Inner Berm Width/Depth Ratio (W_{ibp} / d_{ibp})	87.375	33.854	166.295

	Run Dimensions*	Mean	Min	Max		Run Dimensionless Ratios****	Mean	Min	Max
Run Dimensions*	Run Width (W_{bkfr})	287	226	348	ft	Run Width to Riffle Width (W_{bkfr} / W_{bkf})	0.951	0.748	1.153
	Mean Run Depth (d_{bkfr})	4.06	3.24	4.87	ft	Mean Run Depth to Mean Riffle Depth (d_{bkfr} / d_{bkf})	1.097	0.876	1.316
	Run Cross-Sectional Area (A_{bkfr})	1113	1099	1126	ft	Run Area to Riffle Area (A_{bkfr} / A_{bkf})	1.008	0.996	1.020
	Maximum Run Depth (d_{maxr})	6.73	5.67	7.78	ft	Max Run Depth to Mean Riffle Depth (d_{maxr} / d_{bkf})	1.819	1.532	2.103
	Run Width/Depth Ratio (W_{bkfr} / d_{bkfr})	76.8	46.3	107	ft				

	Glide Dimensions*	Mean	Min	Max		Glide Dimensions & Dimensionless Ratios****	Mean	Min	Max
Glide Dimensions*	Glide Width (W_{bkfg})	348	309	386	ft	Glide Width to Riffle Width (W_{bkfg} / W_{bkf})	1.154	1.027	1.281
	Mean Glide Depth (d_{bkfg})	3.32	2.79	3.84	ft	Mean Glide Depth to Mean Riffle Depth (d_{bkfg} / d_{bkf})	0.897	0.754	1.038
	Glide Cross-Sectional Area (A_{bkfg})	1132	1078	1187	ft	Glide Area to Riffle Area (A_{bkfg} / A_{bkf})	1.026	0.977	1.076
	Maximum Glide Depth (d_{maxg})	5.69	5.39	5.98	ft	Max Glide Depth to Mean Riffle Depth (d_{maxg} / d_{bkf})	1.538	1.457	1.616
	Glide Width/Depth Ratio (W_{bkfg} / d_{bkfg})	109	80.6	138	ft/ft	Glide Inner Berm Width/Depth Ratio (W_{ibg} / d_{ibg})	259.718	230.422	289.014
	Glide Inner Berm Width (W_{ibg})	241	203	279	ft	Glide Inner Berm Width to Glide Width (W_{ibg}/W_{bkfg})	0.713	0.525	0.900
	Glide Inner Berm Depth (d_{ibg})	0.92	0.88	0.96	ft	Glide Inner Berm Depth to Glide Depth (d_{ibg} / d_{bkfg})	0.283	0.251	0.315
	Glide Inner Berm Area (A_{ibg})	223	178	269	ft^2	Glide Inner Berm Area to Glide Area (A_{ibg} / A_{bkfg})	0.196	0.165	0.226

Table 4(b). Summary of the stream morphology and dimensionless ratios from the cross-sections and longitudinal profiles for all bed features (page 2 of 2).

Stream: **North Platte River through Saratoga** Location: **Existing Condition**

Observers: **BR & MG** Date: **06/19/14** Valley Type: **U-AL-FD** Stream Type: **C3**

River Reach Summary Data…..2

Hydraulics

Streamflow: Estimated Mean Velocity at Bankfull Stage (u_{bkf})	4.33	ft/sec	Estimation Method	Continuity, USGS Gage
Streamflow: Estimated Discharge at Bankfull Stage (Q_{bkf})	5200	cfs	Drainage Area	2840 mi^2

Channel Pattern

Geometry	Mean	Min	Max		Dimensionless Geometry Ratios	Mean	Min	Max
Linear Wavelength (λ)	3359	1752	4746	ft	Linear Wavelength to Riffle Width (λ / W_{bkf})	11.146	5.813	15.748
Stream Meander Length (L_m)	3966	2353	5016	ft	Stream Meander Length Ratio (L_m / W_{bkf})	13.160	7.808	16.644
Radius of Curvature (R_c)	818	202	2429	ft	Radius of Curvature to Riffle Width (R_c / W_{bkf})	2.714	0.670	8.060
Belt Width (W_{blt})	1256	905	1606	ft	Meander Width Ratio (W_{blt} / W_{bkf})	4.168	3.003	5.329
Arc Length (L_a)	567	347	973	ft	Arc Length to Riffle Width (L_a / W_{bkf})	1.881	1.151	3.229
Riffle Length (L_r)	407	147	1034	ft	Riffle Length to Riffle Width (L_r / W_{bkf})	1.351	0.488	3.432
Individual Pool Length (L_p)	1573	983	2633	ft	Individual Pool Length to Riffle Width (L_p / W_{bkf})	5.221	3.262	8.738
Pool to Pool Spacing (P_s)	1983	1176	2508	ft	Pool to Pool Spacing to Riffle Width (P_s / W_{bkf})	6.600	4.000	8.300

Channel Profile

Valley Slope (S_{val})	0.0026	ft/ft	Average Water Surface Slope (S)	0.00218	ft/ft	Sinuosity (S_{val} / S)	1.17	
Stream Length (SL)	10767	ft	Valley Length (VL)	9203	ft	Sinuosity (SL / VL)	1.1699	
Low Bank Height (LBH)	start 6.72	ft	Max Depth (d_{max})	start 5.87	ft	Bank-Height Ratio (BHR) (LBH / d_{max})	start 1.1448	
	end 7.32	ft		end 4.95	ft		end 1.4788	

Facet Slopes	Mean	Min	Max		Dimensionless Facet Slope Ratios	Mean	Min	Max
Riffle Slope (S_{rif})	0.004	0.001	0.005	ft/ft	Riffle Slope to Average Water Surface Slope (S_{rif} / S)	1.835	0.459	2.294
Run Slope (S_{run})	0.016	0.004	0.034	ft/ft	Run Slope to Average Water Surface Slope (S_{run} / S)	7.339	1.835	15.596
Pool Slope (S_p)	0.001	0.000	0.001	ft/ft	Pool Slope to Average Water Surface Slope (S_p / S)	0.275	0.083	0.477
Glide Slope (S_g)	0.001	0.001	0.001	ft/ft	Glide Slope to Average Water Surface Slope (S_g / S)	0.413	0.317	0.477
Step Slope (S_s)	N/A			ft/ft	Step Slope to Average Water Surface Slope (S_s / S)			

Max Depths[a]	Mean	Min	Max		Dimensionless Depth Ratios	Mean	Min	Max
Max Riffle Depth (d_{maxrif})	4.51	3.85	5.2	ft	Max Riffle Depth to Mean Riffle Depth (d_{maxrif} / d_{bkf})	1.21892	1.041	1.4054
Max Run Depth (d_{maxrun})	5.06	3.9	5.85	ft	Max Run Depth to Mean Riffle Depth (d_{maxrun} / d_{bkf})	1.36757	1.054	1.5811
Max Pool Depth (d_{maxp})	8.64	7.25	9.46	ft	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})	2.33514	1.959	2.5568
Max Glide Depth (d_{maxg})	3.09	2.15	4.8	ft	Max Glide Depth to Mean Riffle Depth (d_{maxg} / d_{bkf})	0.83514	0.581	1.2973
Max Step Depth (d_{maxs})	N/A			ft	Max Step Depth to Mean Riffle Depth (d_{maxs} / d_{bkf})			

Channel Materials

	Reach[b]	Riffle[c]	Bar		Reach[b]	Riffle[c]	Bar	Protrusion Height[d]	
% Silt/Clay			0	D_{16}			4.24		mm
% Sand			12.66	D_{35}			41.12		mm
% Gravel			31.23	D_{50}		128	76.96		mm
% Cobble			56.11	D_{84}		231	144.99		mm
% Boulder			0	D_{95}			167		mm
% Bedrock			0	D_{100}			177		mm

[a] Min, max & mean depths are measured from Thalweg to bankfull at mid-point of feature for riffles and runs, the deepest part of pools, & at the tail-out of glides.
[b] Composite sample of riffles and pools within the designated reach. [c] Active bed of a riffle. [d] Height of roughness feature above bed.

5.2 HYDRAULIC RELATIONS

Table 5 shows estimates of the bankfull mean velocity for a typical riffle using various methods, including friction factor, relative roughness, and Manning's '*n*' by stream type. The close agreement between a known bankfull discharge at the streamgage site and the predicted bankfull mean velocity values for a different width/depth ratio channel provides assurance that the selected bankfull stage of the riffle cross-sections are correct. The most accurate model to predict mean bankfull velocity is the Manning's '*n*' from relative roughness (R/D_{84}) and friction factor ($\bar{u}/u^*$). The bankfull mean velocity was determined to be 4.35 ft/sec.

Table 5. Estimates of bankfull mean velocity for a typical riffle.

Bankfull VELOCITY & DISCHARGE Estimates					
Stream:	North Platte		Location:	Existing Condition - XS-19 Riffle	
Date:	6/19/2014	Stream Type: C3	Valley Type:	U-AL-FD	
Observers:	BR & MG		HUC:		
INPUT VARIABLES			**OUTPUT VARIABLES**		
Bankfull Riffle Cross-Sectional AREA	1201.97	A_{bkf} (ft^2)	Bankfull Riffle Mean DEPTH	4.15	d_{bkf} (ft)
Bankfull Riffle WIDTH	289.82	W_{bkf} (ft)	Wetted PERMIMETER ~ $(2 * d_{bkf}) + W_{bkf}$	293.40	W_p (ft)
D_{84} at Riffle	231.00	Dia. (mm)	D_{84} (mm) / 304.8	0.76	D_{84} (ft)
Bankfull SLOPE	0.0022	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	4.10	R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	3.01	R / D_{84}
Drainage Area	0.0	DA (mi^2)	Shear Velocity u* $= (gRS)^{1/2}$	0.536	u* (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * Log\{R / D_{84}\}] u^*$	3.74	ft / sec	4500.77	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 2-18, 2-19) $u = 1.49*R^{2/3}*S^{1/2}/n$ $n =$ 0.041	4.35	ft / sec	5224.53	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 2-20) $u = 1.49*R^{2/3}*S^{1/2}/n$ $n =$ 0.032	5.50	ft / sec	6661.00	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2}/n$ $n = 0.39*S^{0.38}*R^{-0.16}$ Note: This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 $n =$ 0.030	5.87	ft / sec	7049.55	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) Darcy-Weisbach (Leopold, Wolman and Miller)	3.82	ft / sec	4586.11	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) Regional Curves u = Q / A Return Period for Bankfull Discharge Q = year		ft / sec		cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A	4.33	ft / sec	5200.00	cfs

5.3 SEDIMENT RELATIONS

Sediment competence, sediment transport capacity, and streambank erosion processes were evaluated as part of the geomorphic assessment and are summarized in the following sections. The sediment relations were evaluated using prediction models developed by Wildland Hydrology (as detailed in Rosgen, 2006). Sediment competence was predicted using dimensionless and dimensional shear stress relations, sediment transport capacity was predicted using the FLOWSED/POWERSED model, and streambank erosion was predicted using the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model (Rosgen, 2006).

5.3.1 Sediment Competence

Sediment competence evaluations are important to determine if the stream has the ability to transport the largest particle sizes made available from its catchment based on the existing bankfull mean depth and slope (Rosgen, 2006). Sediment competence was evaluated using tractive force equations based on bankfull shear stress (depth slope product times the specific weight of water) in addition to critical dimensionless shear stress calculations as summarized in **Table 6**. The largest size particle and a range of bedload sizes potentially transported at the bankfull stage were measured from a bar sample. The largest particle size of 177 mm (**Table 6**) is related to a size larger than the D_{50} of bed material but less than the D_{84} of the bed.

The competence analysis indicates that there is not general mobility of the coarse cobble streambed during the bankfull discharge. The largest size measured with a six-inch Helley-Smith bedload sampler near the bankfull discharge was 62 mm. The results of this analysis using both critical dimensionless shear stress and dimensional shear stress (using Colorado data) indicate potential aggradation or excess sediment deposition (**Table 6**).

Table 6. Sediment competence calculations for a typical riffle using critical dimensionless shear stress and dimensional shear stress relations to determine bed stability (Rosgen, 2006).

Sediment Competence using Dimensional and Dimensionless Shear Stress Methods					
Stream:	**North Platte**		Stream Type:	**C3**	
Location:	**Existing Condition - XS-19 75+87 Rif.**		Valley Type:	**U-AL-FD**	
Observers:	**BR & MG**		Date:	**6/20/2014**	
Enter Required Information for Existing Condition					
128.0	D_{50}	Median particle size of riffle bed material (mm)			
77.0	$\hat{D}_{50}$	Median particle size of bar or sub-pavement sample (mm)			
0.58	D_{max}	Largest particle from bar sample (ft)	**177**	**(mm)**	304.8 mm/ft
0.0022	S	Existing average water surface slope (ft/ft)			
4.15	d	Existing bankfull mean depth (ft)			
1.65	γ_s-γ/γ	Immersed specific gravity of sediment			
Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress					
1.66	$D_{50}/\hat{D}_{50}$	Range: 3 – 7	Use EQUATION 1:	$\tau^* = 0.0834\,(D_{50}/\hat{D}_{50})^{-0.872}$	
1.38	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2:	$\tau^* = 0.0384\,(D_{max}/D_{50})^{-0.887}$	
0.0288	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:	**2**	
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
12.66	**d**	Required bankfull mean depth (ft)	$d = \frac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(use D_{max} in ft)	
Calculate Average Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
0.00665	**S**	Required average water surface slope (ft/ft)	$S = \frac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(use D_{max} in ft)	
Check: ☐ Stable ☑ Aggrading ☐ Degrading					
Sediment Competence Using Dimensional Shear Stress					
0.565		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = existing depth, S = existing slope			
Shields **43**	CO **100**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 3-11)**			
Shields **2.196**	CO **1.230**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 3-11)**			
Shields **16.15**	CO **9.04**	Predicted mean depth required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, S = existing slope	$d = \frac{\tau}{\gamma S}$		
Shields **0.0085**	CO **0.0047**	Predicted slope required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, d = existing depth	$S = \frac{\tau}{\gamma d}$		
Check: ☐ Stable ☑ Aggrading ☐ Degrading					

5.3.2 Sediment Transport Capacity

The FLOWSED model is used to predict total annual sediment yield from suspended sediment, sediment sand, and bedload sediment for flows up to and including the bankfull discharge (Rosgen, 2006). The model requires dimensionless sediment rating curves and flow-duration curves; the inputs to the FLOWSED model are measured bankfull discharge, bankfull concentration of suspended sediment (mg/l), and bankfull bedload (kg/sec). Measured suspended sediment concentration was obtained using a depth integrated sample at the bankfull stage that generated a concentration of 72.7 milligrams/liter (mg/l) at the upstream measurement site, of which 47.5 mg/l is suspended sand concentration (**Table 7**). Measurements of bedload using a six-inch Helley Smith sampler generated a bedload transport rate of 1.17 kg/sec at the bankfull discharge (**Table 7**). The bedload transport rate for 5,200 cfs or 2,840 mi^2 is comparable to other measured data for C3 stream types of similar size in western Montana (**Figure 14**). Bankfull sediment measurements were also taken at a downstream site as indicated in **Table 7**. The total annual sediment yield using the upstream measurements was 18,561 tons/yr, of which 2,250 tons/yr is bedload sediment and 16,311 tons/yr is suspended sediment (**Table 8** and ***APPENDIX V***).

Table 7. Measured values at bankfull stage of bedload, suspended, and suspended sand sediment.

	Bedload Sediment	Total Suspended Sediment Conc.	Suspended Sand Concentration	Washload (Colloidal)
Upstream Measurements	111 tons/day (2.57 lbs/sec)	1,021 tons/day (72.7 mg/l)	667 tons/day (47.5 mg/l)	354 tons/day (25.2 mg/l)
Downstream Measurements	78 tons/day (1.8 lbs/sec)	1,085 tons/day (77.3 mg/l)	543 tons/day (38.7 mg/l)	542 tons/day (38.6 mg/l)
Difference	33 tons/day	– 64 tons/day	+124 tons/day	– 188 tons/day

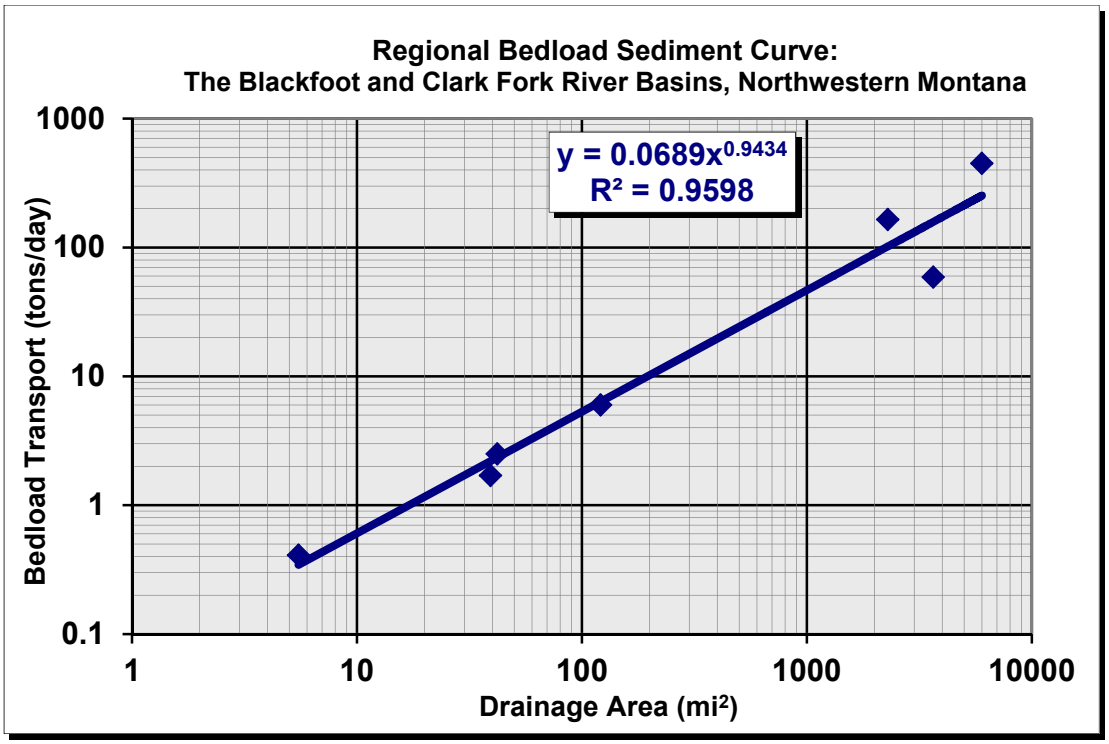


Figure 14. The measured bankfull bedload value of the North Platte River compared to the regional bedload sediment curve for the northwestern Montana.

Using the sediment yield values generated from the FLOWSED model, the POWERSED model was used to determine the disposition of available sediment supply and bed stability. For a stable reference width/depth ratio of 34 scaled for 5200 cfs, the total sediment yield that the downstream channel would be required to transport is 12,887 tons/yr total sediment, 10,641 tons/yr total suspended sand sediment, and 2,246 tons/yr bedload sediment (**Table 8, *APPENDIX V***). The comparison of this available sediment to a downstream riffle reach with a higher width/depth ratio of 69 reduced the sediment yield transport to 4,459 tons/yr total sediment, 3,187 tons/yr suspended sand, and 1,272 tons/yr bedload sediment (**Table 8, *APPENDIX V***). The suspended sand was evaluated separately from total suspended sediment as the sand size is hydraulically controlled and has the potential for deposition in the channel. The reduction of both suspended sand and bedload indicates that there is aggradation or excess deposition on the channel bed. Such deposition leads to flood stage increases, channel instability, and loss of fish habitat.

Comparing the reference sediment yield to a downstream reach with a very high width/depth ratio of 106, the resultant transport was further reduced to 5,106 tons/yr total sediment, 3,429 tons/yr suspended sand, and 1,677 tons/yr bedload (**Table 8, *APPENDIX V***). These additional sediment yield reductions support the general interpretations of flood risk, channel instability, fish habitat impairment, and additional adverse consequences of high to very high width/depth ratios of the North Platte River through Saratoga.

Table 8. Results of the FLOWSED/POWERSED model that predicts total annual sediment yield and sediment transport capacity.

Location	Total Annual Sediment Yield (tons/yr)	Total Suspended Sediment (tons/yr)	Suspended Sand (tons/yr)	Bedload (tons/yr)
FLOWSED: Upstream Supply at Shay Bridge	18,561	16,311		2,250
FLOWSED: Downstream Supply at Bridge St. Bridge	18,919	17,343		1,576
Difference	-358	-1032		674
POWERSED(a): Reference 34 W/d	12,887		10,641	2,246
POWERSED(b): Study Reach XS-19 with 69 W/d	4,459		3,187	1,272
Difference	8,428		7,455	974
POWERSED(a): Reference 34 W/d	12,887		10,641	2,246
POWERSED(c): Study Reach XS-3 with 106 W/d ratio	4,316		3,234	1,083
Difference	8,571		7,407	1,164

5.3.3 Streambank Erosion Processes

The BANCS model (Rosgen, 2006) was used to predict streambank erosion rates for the assessment reach using the Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) ratings. The BANCS model evaluates bank characteristics and flow distribution along river reaches and maps BEHI and NBS ratings commensurate with streambank and channel changes. Annual erosion rates are estimated and then multiplied by the bank height and by a corresponding bank length of a similar condition. BEHI evaluates the susceptibility to erosion for multiple processes, whereas NBS assesses the energy distribution along the streambanks.

Both banks in addition to the banks of an island were evaluated for 10,780 ft of stream length of the North Platte assessment reach. The mapped results of the BEHI ratings for both banks and the island are summarized in **Table 9** and displayed in **Figure 15**. The mapped results of the NBS ratings are shown in **Figure 16**. The annual erosion rates predicted using the Colorado curve in Rosgen (2006) are mapped in **Figure 17**. The total sediment yield from the 10,780 ft of studied stream reach was 3,159.3 tons/yr, or 0.293 tons/yr/ft (**Table 9**). The erosion rates through Saratoga are not as high as some observed conditions farther upstream of the study reach due to hard control stabilization measures (rock rip-rap). An extremely high annual bank erosion rate of 6.76 tons/yr/ft was predicted for 299 ft of bank, making up 2,022 tons/yr, or 64% of the total streambank contribution for 10,780 ft of stream (**Table 9**). This indicates that prioritizing streambank stabilization/restoration work can be effective in reducing major sediment accumulation and land loss.

Erosion from two miles of streambank was determined to contribute 3,159.3 tons of sediment per year, making up 24% of the total sediment yield through the study reach. Not all of the streambank material is routed downsteam, however the suspended sand, contributed from the streambanks has a higher likelihood of deposition as it is hydraulically controlled compared to the washload portion of the suspended sediment. Much of the sand and gravel size sediment is stored in bars and other depositional features of the river. The land loss as well as the sediment contribution is significant as this is comparable to approximately 316 end dump trucks (10 ton capacity) of material leaving the streambanks each year for nearly two miles of this study reach.

Based on observations, very high to extreme streambank erosion rates are evident three miles upstream of the study reach. Values of 0.4 tons/yr/ft of channel were observed for nearly 12,000 ft yielding potentially 4,800 tons (480 truckloads) of sediment per year from upstream of the project reach. It would be advantageous to direct stream restoration works on these actively eroding banks prior to doing the downstream restoration. Not all of the sediment supplied from streambanks is transported out of the basin as considerable quantities are deposited within the channel bed, adding to the impairment, flood risk, and reduced fish habitat in addition to the associated land loss. Streambank erosion is consistently the highest single source of sediment in these fluvial landscapes. The erosion rates are accelerated often due to the lack of dense woody riparian vegetation (cottonwood and willows).

Table 9(a). Annual streambank erosion estimates for 10,780 ft of the North Platte River through Saratoga (LB = Left Bank, RB = Right Bank, LI = Left Island Bank, RI = Right Island Bank, page 1 of 3).

Streambank Erosion Prediction								
Stream:	North Platte - Saratoga			Location: Left Bank				
Graph Used:	Colorado	Total Stream Length (ft): 10780					Date: 6/19/2014	
Observers:	BR, MJG		Valley Type: U-AL-FD				Stream Type: C3	
(1)			(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station (ft)			BEHI Rating (Worksheet 3-11) (adjective)	NBS Rating (Worksheet 3-12) (adjective)	Bank Erosion Rate (Figure 3-9 or 3-10) (ft/yr)	Length of Bank (ft)	Study Bank Height (ft)	Erosion Subtotal [(4)×(5)×(6)] (ft^3/yr)	Unit Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}
1	0-189	LB	E	H	2.747	189.3	7	3641.08	0.92597
2	189-293	LB	L	M	0.075	104.2	5	39.22	0.01812
3	293-701	LB	M	H	0.420	407.4	3	513.66	0.06071
4	701-940	LB	VL	L	0.004	239.2	3	2.77	0.00056
5	940-1939	LB	VL	M	0.009	999.5	3	27.19	0.00131
6	1939-2083	LB	L	L	0.036	143.3	3	15.46	0.00519
7	2083-3001	LB	VL	VL	0.002	918.6	3	4.53	0.00024
8	3001-3216	LB	M	H	0.420	214.9	8	722.68	0.16190
9	3216-3489	LB	M	VH	0.697	273.1	8	1522.52	0.26845
10	3489-3628	LB	VL	VL	0.002	138.8	3	0.68	0.00024
11	3628-3777	LB	L	M	0.075	148.9	2	22.42	0.00725
12	3777-3870	LB	L	VH	0.330	93.0	3	92.09	0.04767
13	3870-3954	LB	H	H	0.575	83.7	6	288.88	0.16621
14	3954-4048	LB	M	H	0.420	94.5	4	158.85	0.08095
15	4048-4176	LB	L	L	0.036	128.1	4	18.43	0.00692
16	4176-4560	LB	L	L	0.036	383.6	3	41.38	0.00519
17	4560-4613	LB	L	M	0.075	52.6	4	15.83	0.01450
18	4613-4774	LB	L	VL	0.017	161.8	6	16.67	0.00496
19	4774-4898	LB	L	VL	0.017	123.6	3	6.37	0.00248
20	4898-5154	LB	L	L	0.036	255.8	6	55.17	0.01039
21	5154-5332	LB	L	M	0.075	178.3	6	80.54	0.02175
22	5332-5605	LB	L	L	0.036	272.6	6	58.81	0.01039
23	5605-5786	LB	VL	L	0.004	181.3	6	4.20	0.00112
24	5786-6330	LB	L	M	0.075	544.2	7	286.73	0.02537
25	6330-6583	LB	VL	L	0.004	252.5	4	3.90	0.00074
26	6583-6980	LB	VL	M	0.009	397.5	4	14.42	0.00175
27	6980-7215	LB	VL	M	0.009	235.3	4	8.54	0.00175
28	7215-7706	LB	VL	M	0.009	490.7	3	13.35	0.00131
29	7706-7988	LB	VL	L	0.004	282.3	3	3.27	0.00056
30	7988-8260	LB	M	L	0.153	272.0	10	415.74	0.07360
31	8260-8656	LB	H	M	0.380	395.5	8	1200.92	0.14621
32	8656-9021	LB	VH	VH	0.872	365.2	8	2547.69	0.33590
33	9021-9276	LB	H	M	0.380	254.9	6	580.55	0.10965
34	9276-9380	LB	L	L	0.036	104.5	4	15.03	0.00692
35	9380-9572	LB	VL	VL	0.002	191.3	5	1.57	0.00040
36	9572-9793	LB	VL	L	0.004	221.3	4	3.42	0.00074
37	9793-9914	LB	M	M	0.253	120.9	8	245.17	0.09764
38	9914-10156	LB	M	M	0.253	241.6	8	489.94	0.09764

Table 9(b). Annual streambank erosion estimates for 10,780 ft of the North Platte River through Saratoga (LB = Left Bank, RB = Right Bank, LI = Left Island Bank, RI = Right Island Bank, page 2 of 3).

Streambank Erosion Prediction

Stream: **North Platte - Saratoga** Location: **Left Bank**

Graph Used: **Colorado** Total Stream Length (ft): **10780** Date: **6/19/2014**

Observers: **BR, MJG** Valley Type: **U-AL-FD** Stream Type: **C3**

	(1) Station (ft)		(2) BEHI Rating (Worksheet 3-11) (adjective)	(3) NBS Rating (Worksheet 3-12) (adjective)	(4) Bank Erosion Rate (Figure 3-9 or 3-10) (ft/yr)	(5) Length of Bank (ft)	(6) Study Bank Height (ft)	(7) Erosion Subtotal [(4)×(5)×(6)] (ft^3/yr)	(8) Unit Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}
39	0-312	RB	Dep. Zone	Dep. Zone	0.000	311.8	0	0.00	0.00000
40	312-450	RB	L	L	0.036	138.3	3	14.92	0.00519
41	450-760	RB	M	M	0.253	309.7	8	628.00	0.09764
42	760-895	RB	L	M	0.075	135.5	6	61.19	0.02175
43	895-1460	RB	Dep. Zone	Dep. Zone	0.000	564.6	0	0.00	0.00000
44	1460-2028	RB	L	M	0.075	567.7	4	170.95	0.01450
45	2028-2790	RB	H	L	0.250	762.5	6	1050.16	0.06632
46	2790-3064	RB	L	M	0.075	273.5	4	82.35	0.01450
47	3064-3341	RB	H	H	0.575	277.4	6	957.60	0.16621
48	3341-3601	RB	L	L	0.036	260.1	5	46.76	0.00865
49	3601-3745	RB	VL	L	0.004	144.1	4	2.23	0.00074
50	3745-3860	RB	L	L	0.036	114.6	4	16.49	0.00692
51	3860-4023	RB	VL	L	0.004	163.1	4	2.52	0.00074
52	4023-4158	RB	VL	L	0.004	135.2	5	2.61	0.00093
53	4158-4221	RB	L	L	0.036	62.7	4	9.01	0.00692
54	4221-4386	RB	L	VH	0.330	164.6	4	217.26	0.06356
55	4386-4550	RB	L	VH	0.330	164.5	3	162.85	0.04767
56	4550-4589	RB	H	H	0.575	38.5	5	110.85	0.13851
57	4589-4693	RB	H	E	1.322	104.7	10	1383.34	0.63642
58	4693-4818	RB	H	H	0.575	124.5	8	573.18	0.22161
59	4818-4986	RB	M	H	0.420	168.3	6	424.34	0.12142
60	4986-5133	RB	M	M	0.253	147.1	4	149.13	0.04882
61	5133-5398	RB	L	M	0.075	264.9	4	79.76	0.01450
62	5398-5715	RB	VL	VL	0.002	317.2	3	1.56	0.00024
63	5715-6069	RB	VL	VL	0.002	354.1	3	1.75	0.00024
64	6069-6512	RB	VL	VL	0.002	442.6	5	3.64	0.00040
65	6512-6919	RB	L	VL	0.017	407.5	4	27.98	0.00331
66	6919-7232	RB	L	VL	0.017	312.7	4	21.48	0.00331
67	7232-7806	RB	M	M	0.253	573.8	7	1018.08	0.08543
68	7806-8019	RB	M	L	0.153	213.4	4	130.51	0.02944
69	8019-8473	RB	H	L	0.250	453.2	6	680.96	0.07234
70	8473-8672	RB	L	L	0.036	199.1	6	42.94	0.01039
71	8672-8785	RB	VL	VL	0.002	113.1	3	0.56	0.00024
72	8785-9142	RB	VL	L	0.004	357.2	3	4.14	0.00056
73	9142-9704	RB	VL	M	0.009	561.8	3	15.28	0.00131
74	9704-9844	RB	M	L	0.153	140.2	20	428.75	0.14721
75	9844-9945	RB	H	M	0.380	101.1	20	767.43	0.36552

Table 9(c). Annual streambank erosion estimates for 10,780 ft of the North Platte River through Saratoga (LB = Left Bank, RB = Right Bank, LI = Left Island Bank, RI = Right Island Bank, page 3 of 3).

Streambank Erosion Prediction

Stream: **North Platte - Saratoga** Location: **Left Bank**

Graph Used: **Colorado** Total Stream Length (ft): **10780** Date: **6/19/2014**

Observers: **BR, MJG** Valley Type: **U-AL-FD** Stream Type: **C3**

	(1) Station (ft)		(2) BEHI Rating (Worksheet 3-11) (adjective)	(3) NBS Rating (Worksheet 3-12) (adjective)	(4) Bank Erosion Rate (Figure 3-9 or 3-10) (ft/yr)	(5) Length of Bank (ft)	(6) Study Bank Height (ft)	(7) Erosion Subtotal [(4)×(5)×(6)] (ft^3/yr)	(8) Unit Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}
76	9945-10244	RB	E	VH	7.027	299.1	20	42029.02	6.76666
77	10244-10321	RB	M	M	0.253	77.3	10	195.92	0.12205
78	10321-10371	RB	L	M	0.075	50.1	6	22.63	0.02175
79	10371-10453	RB	L	M	0.075	82.0	6	37.02	0.02175
80	10453-10656	RB	L	L	0.036	202.2	5	36.35	0.00865
81	10656-10760	RB	VL	VL	0.002	186.5	4	1.23	0.00032
82	0-108	LI	VL	L	0.004	108.2	3	1.25	0.00056
83	108-170	LI	VL	L	0.004	62.0	3	0.72	0.00056
84	170-230	LI	VL	M	0.009	59.5	3	1.62	0.00131
85	230-380	LI	L	M	0.075	150.2	3	33.91	0.01087
86	380-525	LI	L	M	0.000	144.6	2	0.00	0.00000
87	525-595	LI	L	H	0.158	70.1	3	33.16	0.02277
88	595-675	LI	L	VH	0.330	80.4	4	106.17	0.06356
89	675-747	LI	L	H	0.158	72.2	4	45.53	0.03035
90	747-1281	LI	VL	VL	0.002	533.4	3	2.63	0.00024
91	1281-1431	LI	L	H	0.158	149.8	2	47.24	0.01518
92	1431-1781	LI	L	L	0.036	350.0	3	37.75	0.00519
93	0-148	RI	VL	L	0.004	148.3	3	1.72	0.00056
94	148-279	RI	L	L	0.036	130.8	4	18.80	0.00692
95	279-476	RI	L	L	0.036	196.6	3	21.20	0.00519
96	476-572	RI	L	VL	0.017	95.9	0	0.00	0.00000
97	572-760	RI	L	M	0.000	188.4	5	0.00	0.00000
98	760-880	RI	M	M	0.253	120.1	8	243.61	0.09764
99	880-1048	RI	M	M	0.253	168.2	5	213.22	0.06102
100	1048-1467	RI	L	VL	0.017	418.3	2	14.36	0.00165
Sum erosion subtotals in Column (7) for each BEHI/NBS combination							Total Erosion (ft^3/yr)	65615.25	
Convert erosion in ft^3/yr to yds^3/yr {divide *Total Erosion (ft^3/yr)* by 27}							Total Erosion (yds^3/yr)	2430.19	
Convert erosion in yds^3/yr to tons/yr {multiply *Total Erosion (yds^3/yr)* by 1.3}							Total Erosion (tons/yr)	3159.25	
Calculate erosion per unit length of channel {divide *Total Erosion (tons/yr)* by *Total Stream Length (ft)* surveyed}							Unit Erosion Rate (tons/yr/ft)	0.29307	

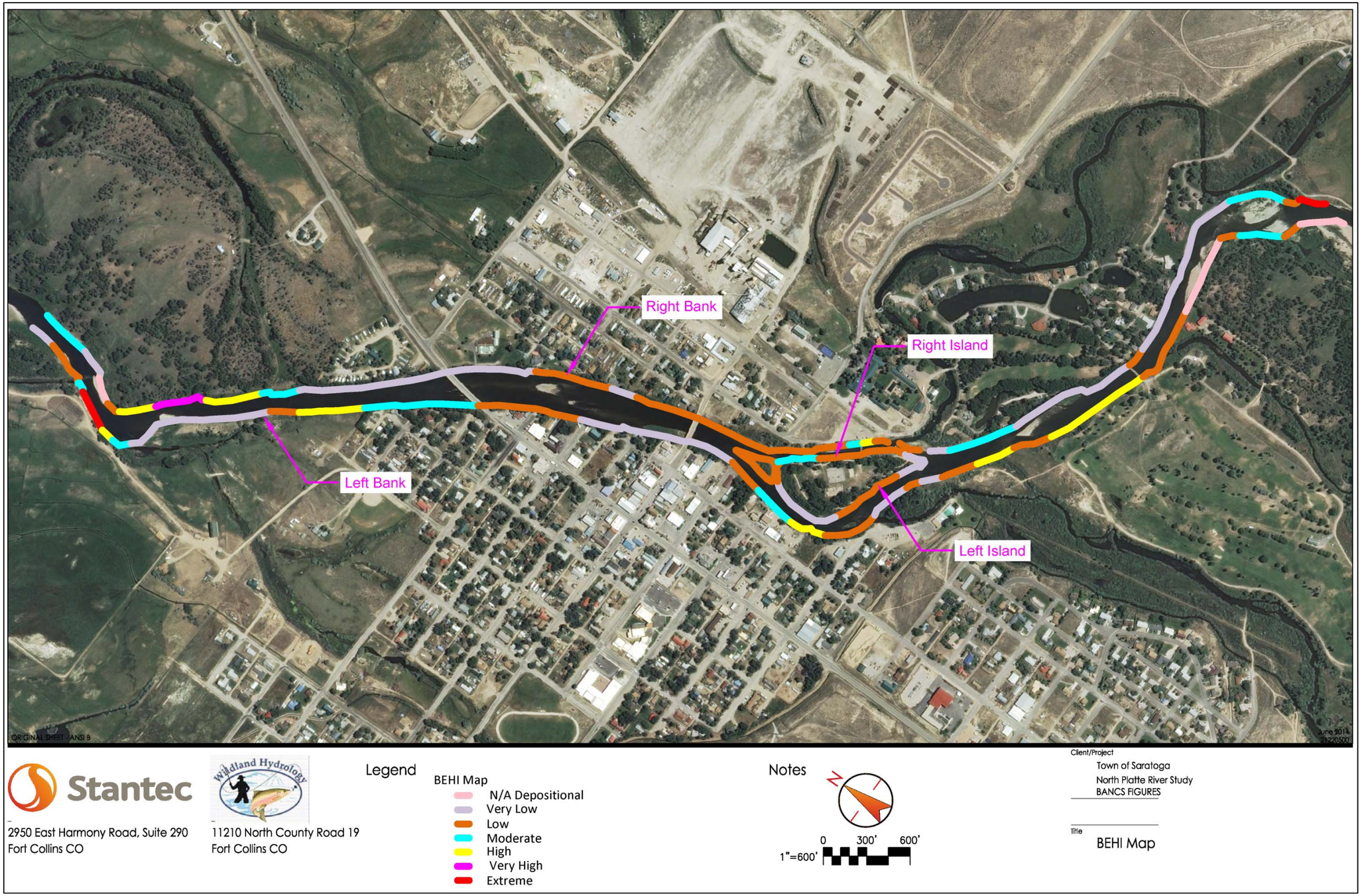


Figure 15. The Bank Erosion Hazard Index (BEHI) Ratings for the North Platte River through Saratoga.

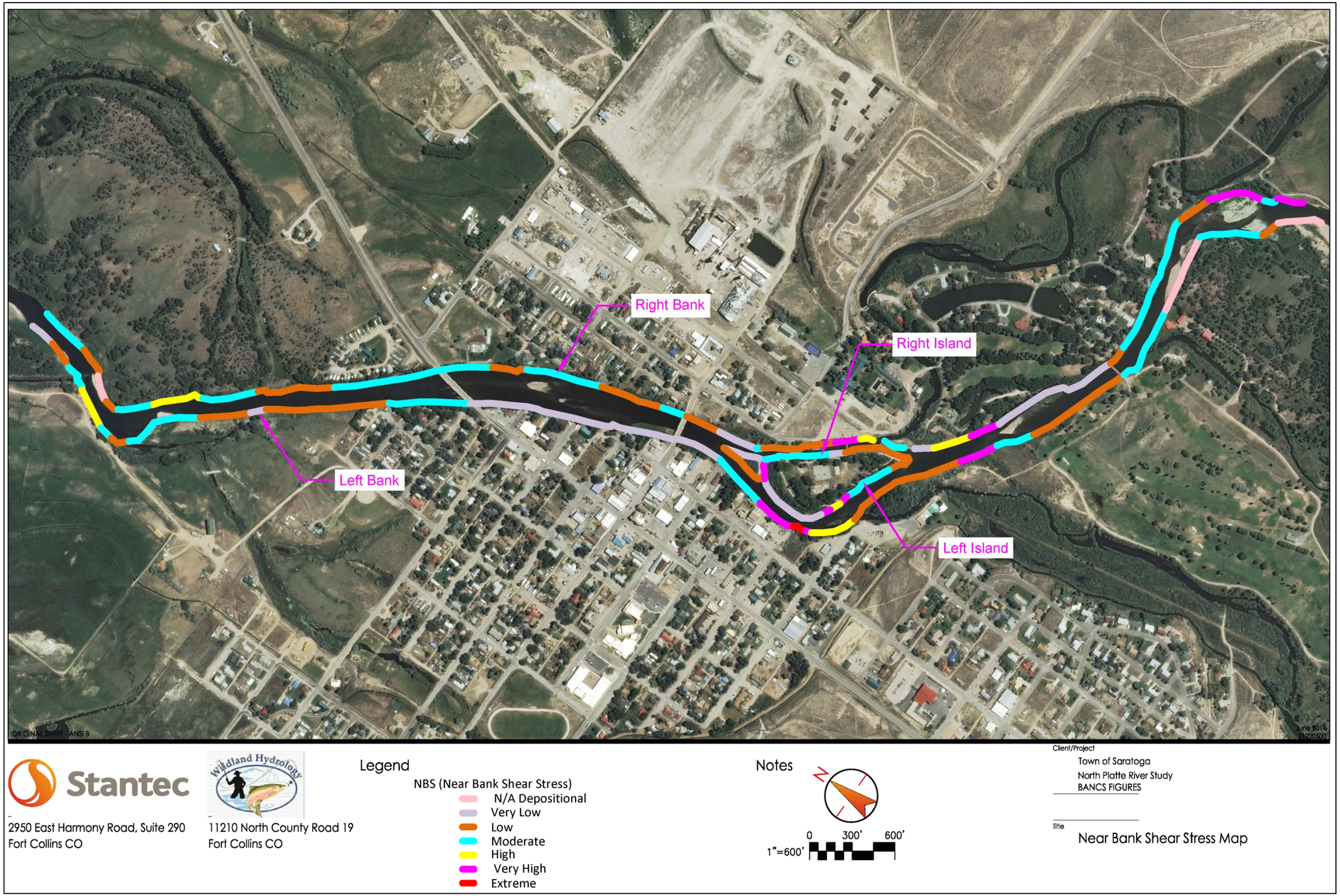


Figure 16. The Near-Bank Stress (NBS) Ratings for the North Platte River through Saratoga.

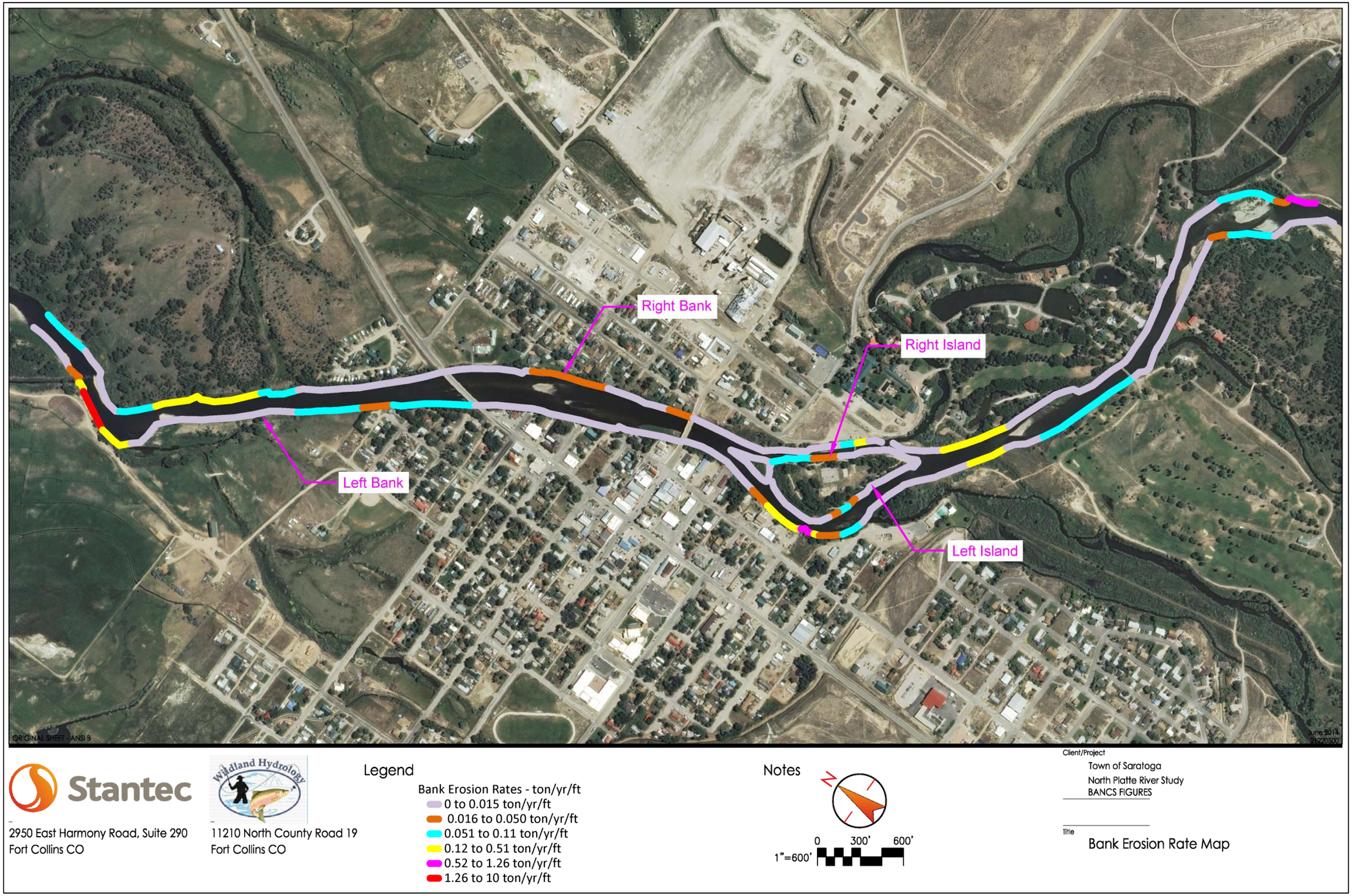


Figure 17. The unit streambank erosion rates for the North Platte River through Saratoga.

5.4 STABILITY RATINGS

The stability analysis is based on the assessment methods presented in Rosgen (2006). The assessment analyzes specific channel stability variables based on field observations and the results of the sediment competence, transport capacity, and streambank erosion estimates. These variables are used in subsequent, process-based, channel stability determinations that address the various processes that are contributing to river impairment, including aggradation, degradation, lateral stability, channel enlargement, and accelerated sediment supply. The overall assessment ratings help to formulate and develop stream restoration designs to offset the limiting factors, instability, and causes and consequences of river impairment. This assessment provides a direct contribution and direction for the proposed conceptual design for stream restoration using natural channel design principles.

5.4.1 Riparian Vegetation

The riparian vegetation assessment indicates departure from the potential riparian plant community related to the composition and density (**Table 10**). Due to riparian vegetation clearing through the town of Saratoga, increased streambank erosion is evident. Along the streambanks where the riparian vegetation was cleared, there is rock rip-rap or hard control measures to help stabilize the banks. Due to grazing pressure or clearing for crops, many streambanks have accelerated erosion rates (see **Figure 17**). An exception to this is the high banks on the pediment terraces where riparian vegetation has little to no influence on streambank erosion. The understory grasses along the reach are bunchgrasses or lawn grass (bluegrass) rather than the potential carex/juncus rhizomatous grasses that should be more prevalent in the composition.

Table 10. Riparian vegetation composition and density for the North Platte River through Saratoga.

Riparian Vegetation					
Stream:	**North Platte River**			Location:	**Existing Condition**
Observers:	**BR & MG**	Reference Reach		Disturbed (Impacted Reach)	X
Stream Type:	**C3**				
Existing Species Composition:	**Cottonwood/Willow/Bunch Grasses/Forbs**			Valley Type:	**U-AL-FD**
Potential Species Composition:	**Cottonwood/Willow/Rhizonomous Grasses**			Date:	**6/19/2014**

Riparian Cover Categories		Percent Aerial Cover*	Percent of Site Coverage**	Species Composition	Percent of Total Species Composition
1. Overstory	Canopy Layer	40-50%*	15%	Cottonwood	99%
				Juniper	1%
					100%
2. Understory	Shrub Layer		30%	Willow	70%
				Alder	20%
				Hawthorne	5%
				Prunus	5%
					100%
3. Ground Level	Herbaceous		50%	Bunchgrass	80%
				Carex/Juncus	10%
				Forbs	10%
					100%
	Leaf or Needle Litter				
	Bare Ground		5%		
			Column Total = 100%		

Remarks:
Condition, vigor and/or usage of existing reach:
Clearing, grazing and urban development
***Based on average conditions for reach as it varies by extent of clearing**

***Based on crown closure**
****Based on basal area to surface area**

5.4.2 Flow Regime

Interpretations for sediment supply and stability relations are based on flow regime and vary by stream type. The North Platte River is a perennial stream with flows dominated primarily by snowmelt runoff (**Table 11**). The North Platte is also affected by regulated streamflows.

Table 11. The flow regime categories for the North Platte River that influence channel characteristics, sediment regime, and biological interpretations.

Flow Regime

Stream:	**North Platte River**					Stream Type:	**C3**	
Location:	**Existing Condition**					Valley Type:	**U-AL-FD**	
Observers:	**BR & MG**					Date:	**6/19/2014**	
List ALL COMBINATIONS that APPLY.....☞	**P1**	**P7**						

General Category

E	***Ephemeral stream channel:*** Flows only in response to precipitation.
S	***Subterranean stream channel:*** Flows parallel to and near the surface for various seasons – a sub-surface flow that follows the stream bed.
I	***Intermittent stream channel:*** Surface water flows discontinuously along its length. Often associated with sporadic or seasonal flows and also with Karst (limestone) geology where losing/gaining reaches create flows that disappear then reappear farther downstream.
P	***Perennial stream channels:*** Surface water persists yearlong.

Specific Category

1	Seasonal variation in streamflow dominated primarily by snowmelt runoff.
2	Seasonal variation in streamflow dominated primarily by stormflow runoff.
3	Uniform stage and associated streamflow due to spring-fed condition, backwater, etc.
4	Streamflow regulated by glacial melt.
5	Ice flows/ice torrents from ice dam breaches.
6	Alternating flow/backwater due to tidal influence.
7	Regulated streamflow due to diversions, dam release, dewatering, etc.
8	Altered due to development, such as urban streams, cut-over watersheds, or vegetation conversions (forested to grassland) that change flow response to precipitation events.
9	Rain-on-snow generated runoff.

5.4.3 Stream Size & Order

Stream order gives an approximate reference for source areas of contribution. Stream sizes expressed as bankfull width ranges also help to summarize data by indicating the approximate channel width. The North Platte River is a 6th order stream type with a typical bankfull width of 290 ft (**Table 12**).

Table 12. Stream order and stream size categories for the North Platte River through Saratoga.

Stream Size and Order			
Stream:	**North Platte River**		
Location:	**Existing Condition**		
Observers:	**BR & MG**	Stream Type:	**C3**
Valley Type:	**U-AL-FD**	Date:	**6/19/2014**

Stream Size Category and Order ☞			S-10(6)
Category	**STREAM SIZE: Bankfull Width**		**Check (✓) Appropriate Category**
	meters	**feet**	
S-1	0.305	<1	☐
S-2	0.3 – 1.5	1 – 5	☐
S-3	1.5 – 4.6	5 – 15	☐
S-4	4.6 – 9.0	15 – 30	☐
S-5	9.0 – 15.0	30 – 50	☐
S-6	15.0 – 22.8	50 – 75	☐
S-7	22.8 – 30.5	75 – 100	☐
S-8	30.5 – 46.0	100 – 150	☐
S-9	46 – 76	150 – 250	☐
S-10	76 – 107	250 – 350	☑
S-11	107 – 150	350 – 500	☐
S-12	150 – 305	500 – 1000	☐
S-13	>305	>1000	☐

Stream Order

Add categories in parenthesis for specific stream order of reach. For example, a third-order stream with a bankfull width of 6.1 meters (20 feet) would be indexed as: S-4(3).

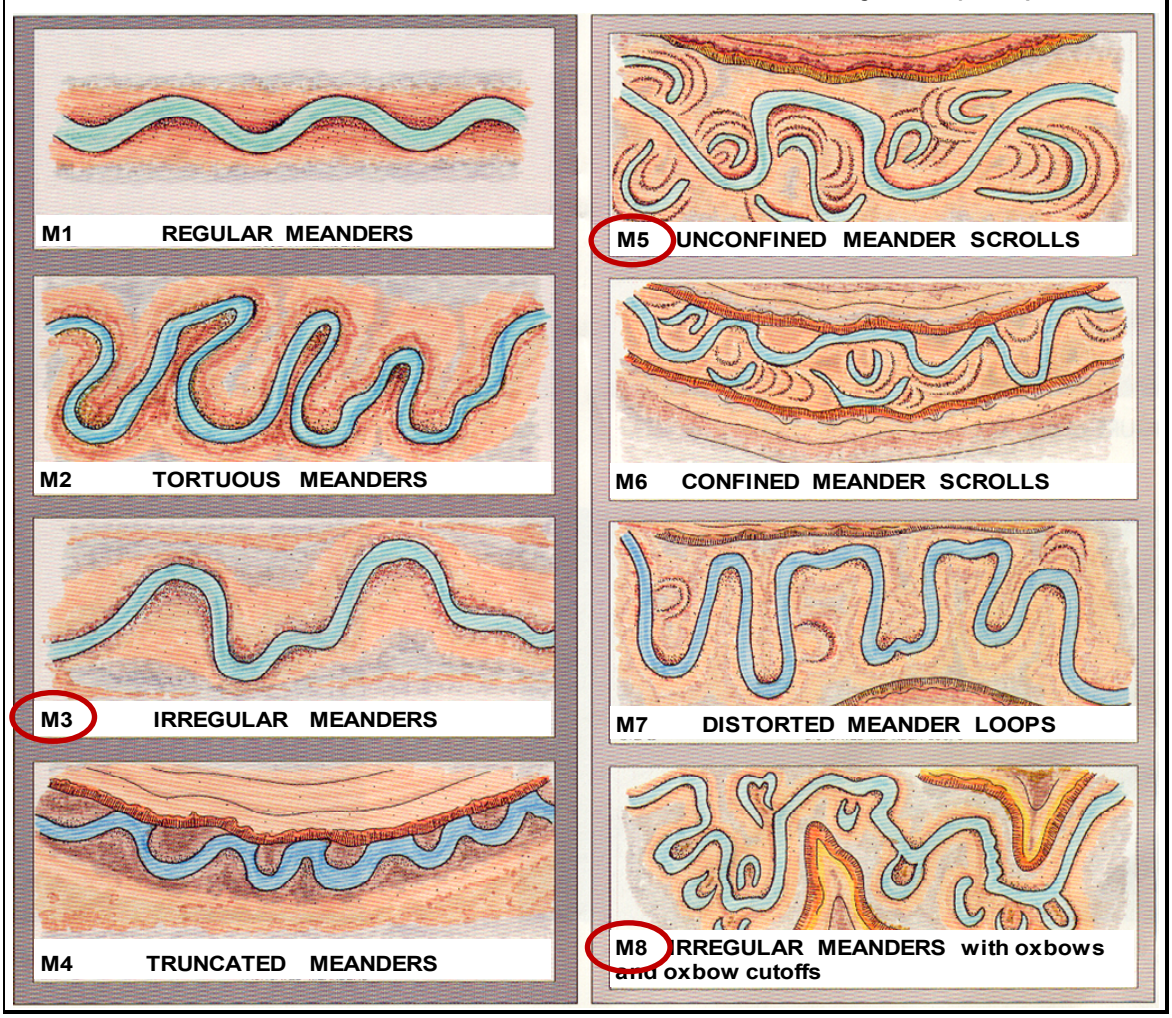
5.4.4 Meander Patterns

Meander patterns express adjustments to past events or impacts. They also indicate the direction and mode of lateral adjustment. The patterns indicate a central tendency for the "wandering river," lateral migration, and other related processes when compared using time-trend aerial photography. The North Platte River is associated with irregular meanders, unconfined meander scrolls, and irregular meanders with oxbows and oxbow cutoffs (**Table 13**). Meander patterns are used in the assessment of lateral stability.

Table 13. Meander pattern relations for the North Platte River used for interpretations for river stability (modified from Galay *et al*., 1973; Rosgen, 1996, 2006).

Meander Patterns					
Stream: **North Platte River**		Stream Type: **C3**			
Location: **Existing Condition**		Valley Type: **U-AL-FD**			
Observers: **BR & MG**		Date: **6/19/2014**			
List ALL CATEGORIES that APPLY ☞	**M3**	**M5**	**M8**		

Various Meander Pattern Variables modified from Galay et al. (1973)



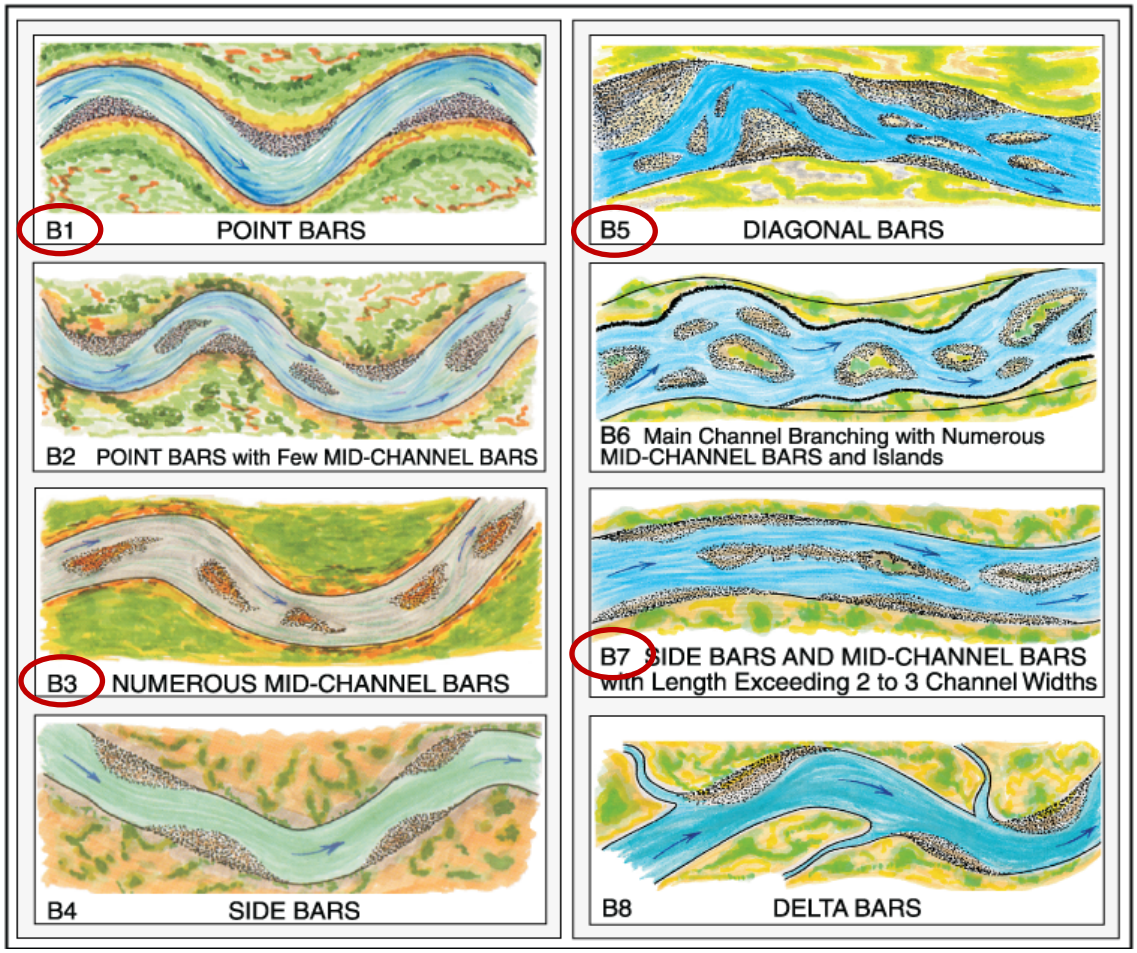
5.4.5 Depositional Patterns

The depositional pattern ratings describe the nature and extent of bar features in rivers. The North Platte River has point bars, numerous mid-channel bars, diagonal bars, side bars and mid-channel bars with lengths exceeding two to three channel widths (**Table 14**). The presence of transverse bars and mid channel bars are an indication of a high width/depth ratio, lack of sediment transport capacity, and a high sediment supply. The depositional pattern ratings are used in the assessments of lateral and vertical stability.

Table 14. Depositional patterns used for stability assessments (modified from Galay *et al*., 1973; Rosgen, 1996, 2006).

Depositional Patterns						
Stream:	**North Platte River**			Stream Type:	**C3**	
Location:	**Existing Condition**			Valley Type:	**U-AL-FD**	
Observers:	**BR & MG**			Date:	**6/19/2014**	
List ALL CATEGORIES that APPLY ☞	**B1**	**B3**	**B5**	**B7**		

Various Depositional Features modified from Galay et al. (1973)



5.4.6 Channel Blockages

The North Platte River was not observed to include any channel blockages such as debris or floatable material (**Table 15**). The channel blockage rating is used in the vertical stability assessment for excess sediment and aggradation.

Table 15. Channel blockage category for the North Platte River used to evaluate channel stability.

Channel Blockages			
Stream:	**North Platte River**	Stream Type:	**C3**
Location:	**Existing Condition**	Valley Type:	**U-AL-FD**
Observers:	**BR & MG**	Date:	**6/19/2014**

Description/Extent		Materials that upon placement into the active channel or flood-prone area may cause adjustments in channel dimensions or conditions due to influences on the existing flow regime.	Check (✓) all that apply
D1	None	Minor amounts of small, floatable material.	☑
D2	Infrequent	Debris consists of small, easily moved, floatable material, e.g., leaves, needles, small limbs, and twigs.	☐
D3	Moderate	Increasing frequency of small- to medium-sized material, such as large limbs, branches, and small logs, that when accumulated affect 10% or less of the active channel cross-sectional area.	☐
D4	Numerous	Significant build-up of medium- to large-sized materials, e.g., large limbs, branches, small logs, or portions of trees, occupying 10–30% of the active channel cross-sectional area.	☐
D5	Extensive	Debris "dams" of predominantly larger materials, e.g., branches, logs, and trees, occupying 30–50% of the active channel cross-sectional area, often extending across the width of the active channel.	☐
D6	Dominating	Large, somewhat continuous, debris "dams," extensive in nature and occupying over 50% of the active channel cross-sectional area. Such accumulations may divert water into the flood-prone areas and form fish migration barriers, even when flows are at less than bankfull.	☐
D7	Beaver Dams: Few	An infrequent number of dams spaced such that normal streamflow and expected channel conditions exist in the reaches between dams.	☐
D8	Beaver Dams: Frequent	Frequency of dams is such that backwater conditions exist for channel reaches between structures where streamflow velocities are reduced and channel dimensions or conditions are influenced.	☐
D9	Beaver Dams: Abandoned	Numerous abandoned dams, many of which have filled with sediment or breached, initiating a series of channel adjustments, such as streambank erosion, lateral migration, avulsion, aggradation, or degradation.	☐
D10	Human Influences	Structures, facilities, or materials related to land uses or development located within the flood-prone area, such as diversions or low-head dams, controlled by-pass channels, velocity control structures, and various transportation encroachments that have an influence on the existing flow regime, such that significant channel adjustments occur.	☐

5.4.7 Degree of Channel Incision

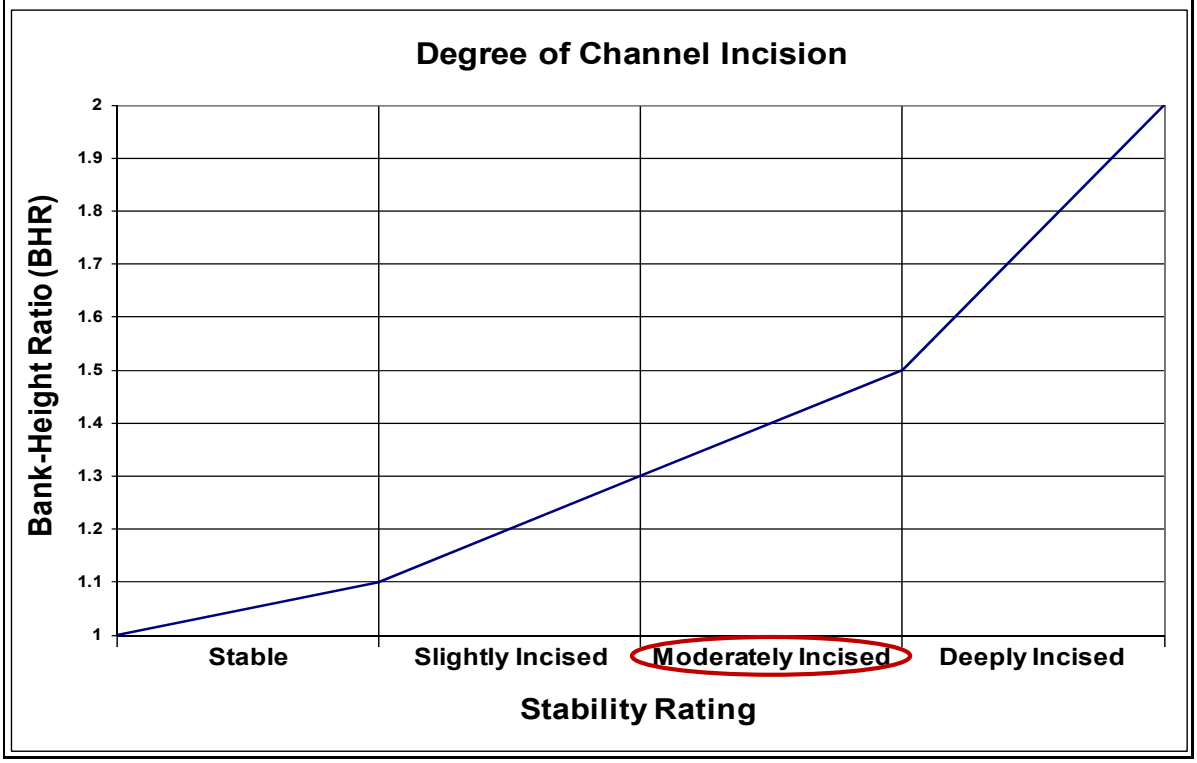
Channel incision is created by the abandonment of an active floodplain and a lowering of local base level. The degree of channel incision is determined by the Bank-Height Ratio (BHR). BHR is calculated by dividing the lowest bank height by the bankfull maximum depth. The North Platte River has an average bank-height ratio of 1.5, which indicates increased streambank erosion due to high streambanks. This makes the rooting depth and density of riparian vegetation difficult to establish and stabilize the actively eroding streambanks. Although the channel incision reduces the frequency of over-bank flows, it adds to the high sediment supply and instability. The current channel is not entrenched but it is incised, meaning that flows greater than bankfull are still able to access the floodplain. The BHR rating is used to assess vertical stability for channel incision and degradation.

Table 16. Bank-Height Ratio (BHR) ranges to corresponding stream stability ratings to infer degree of channel incision for the North Platte River through Saratoga.

Degree of Channel Incision			
Stream:	**North Platte River**	Stream Type:	**C3**
Location:	**Existing Condition**	Valley Type:	**U-AL-FD**
Observers:	**BR & MG**	Date:	**6/19/2014**

Low Bank Height:	**9.3**	Bank-Height Ratio (BHR):	**1.48**
Bankfull Max Depth:	**6.3**		

Degree of Channel Incision Stability Rating ☞	**Mod. Incised**



5.4.8 Width/Depth Ratio State

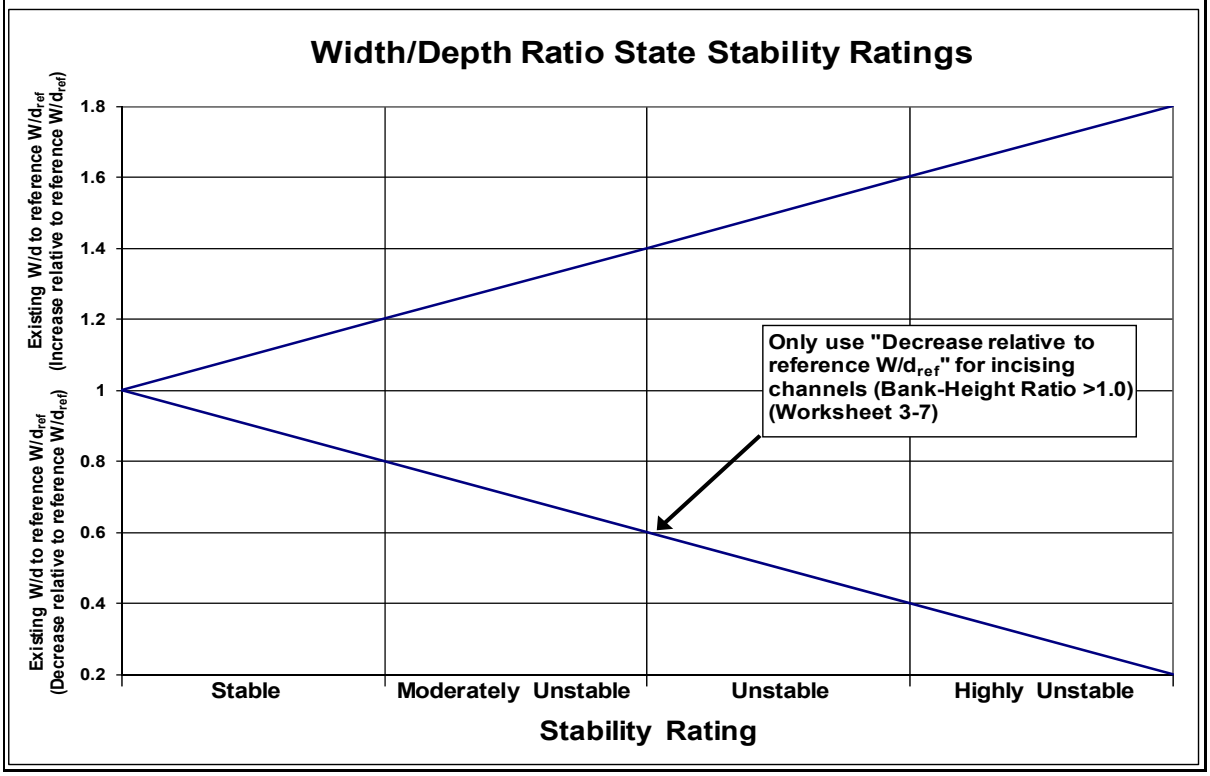
The width/depth ratio state evaluates the departure of the existing condition to the reference width/depth ratio that represents the same valley type and stream type. One of the most prevalent problems related to impairment of the North Platte assessment reach is the extreme high width/depth ratios that vary from 63.4 to 106 (*Highly Unstable* rating, **Table 17**). A typical reference C3 stream type in the same valley type has a width/depth ratio that ranges from 21 to34. The high width/depth ratio channel reduces the ability to transport sediment due to decreased unit stream power (velocity multiplied by shear stress), reduced instream cover for fish, and decreased stream velocities leading to increased flood risk. The width/depth ratio stability rating is used to assess lateral and vertical stability. The width/depth ratio will need be corrected to reduce the stated adverse consequences.

Table 17. Stability ratings based on the departure of width/depth ratio from the reference condition for the North Platter River through Saratoga.

Width/Depth Ratio State			
Stream:	**North Platte River**	Stream Type:	**C3**
Location:	**Existing Condition**	Valley Type:	**U-AL-FD**
Observers:	**BR & MG**	Date:	**6/19/2014**

Existing Width/Depth Ratio (W/d):	**69.8**	Existing W/d to Reference W/d_{ref} :	**2.05**
Reference Width/Depth Ratio (W/d_{ref}):	**34**		

Width/Depth Ratio State Stability Rating ☞	**Highly Unstable**



5.4.9 Degree of Confinement

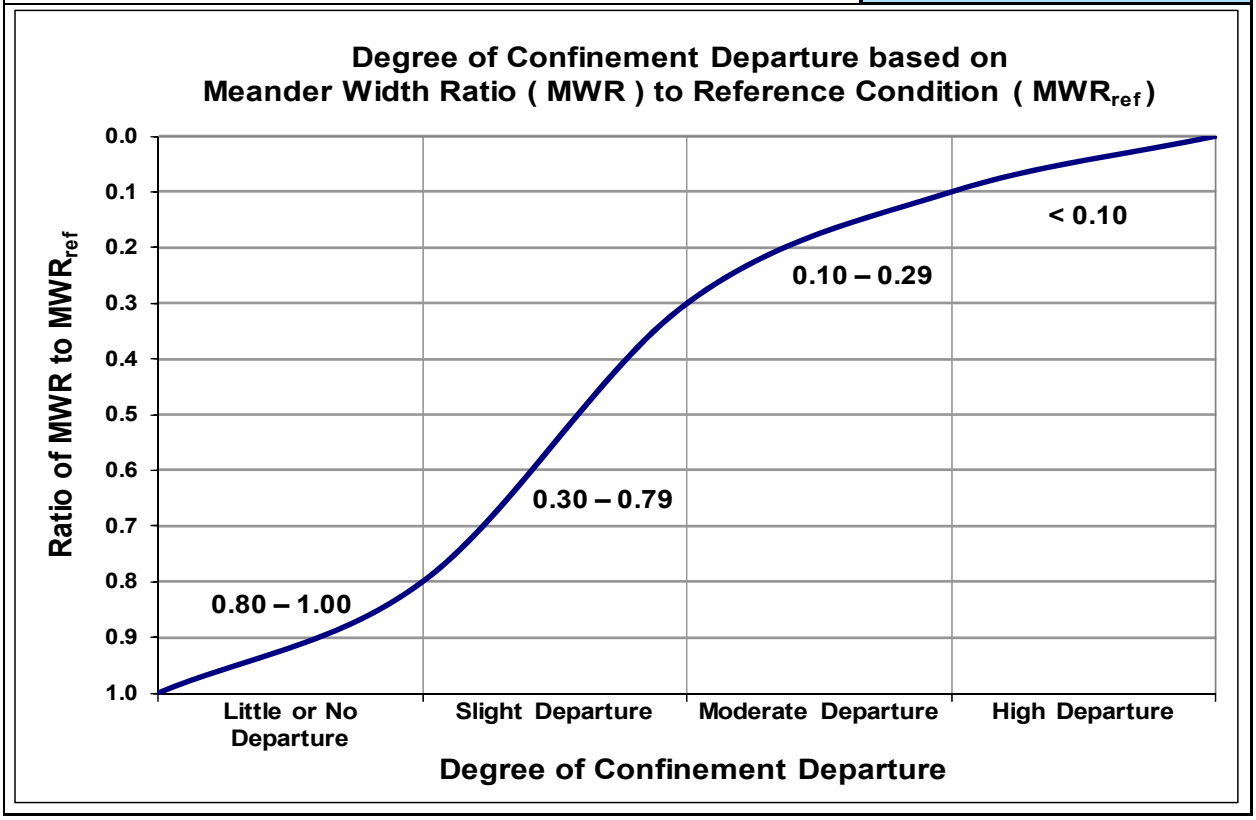
The degree of channel confinement is measured by comparing the Meander Width Ratio (MWR: belt width divided by bank full width) of the assessment reach to the reference condition. The Meander Width Ratio for the North Platte assessment reach is similar to that of the reference condition (**Table 18**). This rating is used to assess lateral and vertical stability.

Table 18. Degree of confinement departure based on Meander Width Ratio (MWR) divided by the reference condition Meander Width Ratio (MWR_{ref}) for the North Platte River through Saratoga.

Degree of Confinement			
Stream:	**North Platte River**	Stream Type:	**C3**
Location:	**Existing Condition**	Valley Type:	**U-AL-FD**
Observers:	**BR & MG**	Date:	**6/19/2014**

Existing Meander Width Ratio (MWR):	**4**	Ratio of MWR to MWR_{ref} :	**0.89**
Reference Meander Width Ratio (MWR_{ref}):	**4.5**		

Degree of Confinement Stability Rating ☞	**No Departure**



5.4.10 Pfankuch Stability Rating

The Pfankuch channel stability rating by stream type is used as a preliminary interpretation for potential vertical stability, width/depth ratio condition, and sediment supply. The higher the numerical score, the higher the sediment supply. The rating is also used to select appropriate dimensionless bedload and suspended sediment rating curves in the FLOWSED/POWERSED model. Last, the rating is used to determine an overall sediment supply rating.

The North Platte assessment reach has a Pfankuch stability rating of 89, which rates as a "fair" stability and is in the mid-range of ratings often observed in C3 stream types (**Table 19**). To improve the ratings, streambank erosion needs to be reduced and the deposition related to channel bars needs to be addressed.

Table 19. Pfankuch (1975) channel stability rating, as modified by Rosgen (1996, 2006), for the North Platte River through Saratoga.

Stream: North Platte River **Location:** Existing Condition **Valley Type:** U-AL-FD **Observers:** BR & MG **Date:** 6/19/2014

Location	Key	Category	Excellent Description	Excellent Rating	Good Description	Good Rating	Fair Description	Fair Rating	Poor Description	Poor Rating
Upper banks	1	Landform slope	Bank slope gradient <30%.	2	Bank slope gradient 30–40%.	4	Bank slope gradient 40–60%.	6	Bank slope gradient > 60%.	8
	2	Mass erosion	No evidence of past or future mass erosion.	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly yearlong.	9	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	12
	3	Debris jam potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	6	Moderate to heavy amounts, predominantly larger sizes.	8
	4	Vegetative bank protection	> 90% plant density. Vigor and variety suggest a deep, dense, soil-binding root mass.	3	70–90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	50–70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9	<50% density plus fewer species and less vigor indicating poor, discontinuous, and shallow root mass.	12
Lower banks	5	Channel capacity	Bank heights sufficient to contain the bankfull stage. Width/depth ratio departure from reference width/depth ratio = 1.0. Bank-Height Ratio (BHR) = 1.0.	1	Bankfull stage is contained within banks. Width/depth ratio departure from reference width/depth ratio = 1.0–1.2. Bank-Height Ratio (BHR) = 1.0–1.1.	2	Bankfull stage is not contained. Width/depth ratio departure from reference width/depth ratio = 1.2–1.4. Bank-Height Ratio (BHR) = 1.1–1.3.	3	Bankfull stage is not contained; over-bank flows are common with flows less than bankfull. Width/depth ratio departure from reference width/depth ratio > 1.4. Bank-Height Ratio (BHR) > 1.3.	4
	6	Bank rock content	> 65% with large angular boulders. 12"+ common.	2	40–65%. Mostly boulders and small cobbles 6–12".	4	20–40%. Most in the 3–6" diameter class.	6	<20% rock fragments of gravel sizes, 1–3" or less.	8
	7	Obstructions to flow	Rocks and logs firmly imbedded. Flow pattern w/o cutting or deposition. Stable bed.	2	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	4	Moderately frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
	8	Cutting	Little or none. Infrequent raw banks <6".	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6	Significant. Cuts 12–24" high. Root mat overhangs and sloughing evident.	12	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
	9	Deposition	Little or no enlargement of channel or point bars.	4	Some new bar increase, mostly from coarse gravel.	8	Moderate depostion of new gravel and coarse sand on old and some new bars.	12	Extensive deposit of predominantly fine particles. Accelerated bar development.	16
Bottom	10	Rock angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges. Surfaces smooth and flat.	2	Corners and edges well-rounded in two dimensions.	3	Well-rounded in all dimensions, surfaces smooth.	4
	11	Brightness	Surfaces dull, dark, or stained. Generally not bright.	1	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright, i.e., 35–65% mixture range.	3	Predominantly bright, > 65%, exposed or scoured surfaces.	4
	12	Consolidation of particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	4	Mostly loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
	13	Bottom size distribution	No size change evident. Stable material 80–100%.	4	Distribution shift light. Stable material 50–80%.	8	Moderate change in sizes. Stable materials 20–50%.	12	Marked distribution change. Stable materials 0–20%.	16
	14	Scouring and deposition	<5% of bottom affected by scour or deposition.	6	5–30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30–50% affected. Deposits and scour at obstructions, constrictions, and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
	15	Aquatic vegetation	Abundant growth moss-like, dark green perennial. In swift water too.	1	Common. Algae forms in low velocity and pool areas. Moss here too.	2	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3	Perennial types scarce or absent. Yellow-green, short-term bloom may be present.	4
			Excellent Total =	**6**	**Good Total =**	**26**	**Fair Total =**	**57**	**Poor Total =**	**0**

Stream type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6
Good (Stable)	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98
Fair (Mod. unstable)	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125
Poor (Unstable)	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+

Stream type	DA3	DA4	DA5	DA6	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	G1	G2	G3	G4	G5	G6
Good (Stable)	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107
Fair (Mod. unstable)	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120
Poor (Unstable)	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+

Grand Total =	89
Existing Stream Type =	C3
*Potential Stream Type =	C3
Modified channel stability rating =	FAIR

*Rating is adjusted to *potential* stream type, not existing stream type

5.4.11 Stream Succession Stage Shift

A change in stream type from the potential condition can lead to long-term significant channel adjustments. The North Platte assessment reach is related to a shift from a stable C3 stream type with a low width/depth ratio to a C3 stream type with very high to extreme width/depth ratios (**Table 20**). The *Moderately Unstable* rating indicates vertical instability and potential channel enlargement.

Table 20. The stability rating for the stream type stage shift for the North Platte River through Saratoga.

Stream Succession Stage Shifts			
Stream:	**North Platte River**	Stream Type:	**C3**
Location:	**Existing Condition**	Valley Type:	**U-AL-FD**
Observers:	**BR & MG**	Date:	**6/19/2014**

Stream Type Stage Shifts	**Stability Rating (Check ✓ Appropriate Rating)**
Stream Type at Potential, (C→E), (F_b→B), (F→B_c), (F→C), (G→B), (D→C)	☐ Stable
(E→C), (B→High W/d B), (C→High W/d C)	☑ Moderately Unstable
(G_c→F), (G→F_b), (F→D), (C→F)	☐ Unstable
(C→D), (A→G), (B→G), (D→G), (C→G), (E→G), (E→A)	☐ Highly Unstable

5.4.12 Lateral Stability

Lateral stability is assessed using the five field stability indicators identified in the above sections; four of the five categories for the North Platte assessment reach are rated as *Unstable* or *Highly Unstable* (**Table 21**). The insight into this rating identifies the stability indicators that need to be mitigated or altered to reduce the lateral instability. Decreasing the width/depth ratio and stabilizing streambanks will correct the variables identified as impaired. Riparian vegetation and bank stability structures will be proposed by specific location to help offset these ratings.

Table 21. The lateral stability prediction summary for the North Platte River through Saratoga.

Lateral Stability Prediction					
Stream: **North Platte River**			Stream Type: **C3**		
Location: **Existing Condition**			Valley Type: **U-AL-FD**		
Observers: **BR & MG**			Date: **6/19/2014**		
Lateral stability criteria (choose one stability category for each criterion 1–5)	**Lateral Stability Categories**				**Selected Points (from each row)**
	Stable	***Moderately Unstable***	***Unstable***	***Highly Unstable***	
1 W/d Ratio State	< 1.2	1.2 – 1.4	1.4 – 1.6	> 1.6	**8**
	(2)	**(4)**	**(6)**	**2.1 (8)**	
2 Depositional Patterns	**B1**, B2	B4, B8	**B3**	**B5**, B6, **B7**	**4**
	(1)	**(2)**	**(3)**	**(4)**	
3 Meander Patterns	M1, **M3**, M4		M2, **M5**, M6, M7, **M8**		**3**
	(1)		**(3)**		
4 Streambank Erosion: Unit Rate	< 0.006	0.006 – 0.04	0.041 – 0.07	> 0.07	**8**
	(2)	**(4)**	**(6)**	**(8)**	
5 Degree of Confinement (MWR / MWR_{ref})	> 0.8	0.3 – 0.79	0.1 – 0.29	< 0.1	**1**
	0.89 (1)	**(2)**	**(3)**	**(4)**	
				Total Points	**24**
	Lateral Stability Category Point Range				
Overall Lateral Stability Category (use total points and check ✓ stability rating)	***Stable*** **< 10** ☐	***Moderately Unstable*** **10 – 12** ☐	***Unstable*** **13 – 21** ☐	***Highly Unstable*** **> 21** ☑	

5.4.13 Vertical Stability: Excess Sediment and Aggradation

Vertical stability for aggradation is assessed using six stability indicators as previously identified; five of the six categories for the North Platte rate as *Aggradation* primarily due to the sediment consequence, width/depth ratio, and depositional patterns (**Table 22**). The proposed conceptual design must be assessed for sediment competence and sediment transport capacity. Significant channel shaping will be required to reverse the consequences of vertical instability, added flood risk, and decreased fish habitat due to a lack of instream cover.

Table 22. The vertical stability prediction summary for excess deposition and aggradation for the North Platte River through Saratoga.

Vertical Stability Prediction for Excess Deposition and Aggradation					
Stream: **North Platte River**			Stream Type: **C3**		
Location: **Existing Condition**			Valley Type: **U-AL-FD**		
Observers: **BR & MG**			Date: **6/19/2014**		
Vertical Stability Criteria (choose one stability category for each criterion 1–6)	**Vertical Stability Categories for Excess Deposition / Aggradation**				**Selected Points (from each row)**
	No Deposition	***Moderate Deposition***	***Excess Deposition***	***Aggradation***	
1 Sediment Competence	Sufficient depth and slope to transport largest size available	Trend toward insufficient depth or slope-slightly incompetent	Cannot move D_{35} of bed material and/or D_{100} of bar material	Cannot move D_{16} of bed material and/or D_{100} of bar or sub-pavement size	**8**
	(2)	**(4)**	**(6)**	**(8)**	
2 Sediment Capacity (POWERSED)	Sufficient capacity to transport annual load	Trend toward insufficient sediment capacity	Reduction up to 25% of annual sediment yield of bedload or suspended sand	Reduction over 25% of annual sediment yield for bedload or suspended sand	**8**
	(2)	**(4)**	**(6)**	**(8)**	
3 W/d Ratio State	< 1.2	1.2 – 1.4	1.4 – 1.6	> 1.6	**8**
	(2)	**(4)**	**(6)**	**2.1 (8)**	
4 Stream Succession Stage Shifts	Current stream type at potential or does not indicate deposition/ aggradation	(E→C)	(B→High W/d B), **(C→High W/d C)**, (C→F), (G_c→F), (G→F_b)	(C→D), (F→D)	**6**
	(2)	**(4)**	**(6)**	**(8)**	
5 Depositional Patterns	**B1**	B2, B4	**B3, B5**	B6, **B7**, B8	**4**
	(1)	**(2)**	**(3)**	**(4)**	
6 Debris / Blockages	D1, D2, D3	D4, D7	D5, D8	D6, D9, D10	**1**
	D1 (1)	**(2)**	**(3)**	**(4)**	
				Total Points	**35**
	Vertical Stability Category Point Range for Excess Deposition and Aggradation				
Vertical Stability for Excess Deposition / Aggradation (use total points and check ✓ stability rating)	***No Deposition*** **< 15** ☐	***Moderate Deposition*** **15 – 20** ☐	***Excess Deposition*** **21 – 30** ☐	***Aggradation*** **> 30** ☑	

5.4.14 Vertical Stability: Channel Incision and Degradation

Vertical stability for degradation is assessed using the five stability indicators identified in the above sections; the North Platte rating indicates that the C3 stream type is incised but not entrenched (total vertical containment) (**Table 23**). The potential for increased channel incision is very low due to the existing high width/depth ratio; however, streambank erosion is accelerated due to the bank-height ratios of 1.5. The bank-height ratio must be lowered to reduce the instability due to channel incision and will be addressed with the proposed conceptual design plan.

Table 23. The vertical stability prediction summary for channel incision and degradation for the North Platte River through Saratoga.

Vertical Stability Prediction for Channel Incision and Degradation					
Stream: **North Platte River**			Stream Type: **C3**		
Location: **Existing Condition**			Valley Type: **U-AL-FD**		
Observers: **BR & MG**			Date: **6/19/2014**		
Vertical Stability Criteria (choose one stability category for each criterion 1–5)	**Vertical Stability Categories for Channel Incision / Degradation**				**Selected Points (from each row)**
	Not Incised	***Slightly Incised***	***Moderately Incised***	***Degradation***	
1 Sediment Competence	Does not indicate excess competence	Trend to move larger sizes than D_{100} of bar or D_{84} of bed	D_{100} of bed moved	Particles much larger than D_{100} of bed moved	**2**
	(2)	**(4)**	**(6)**	**(8)**	
2 Sediment Capacity (POWERSED)	Does not indicate excess capacity	Slight excess energy: up to 10% increase above reference	Excess energy sufficient to increase load up to 50% of annual load	Excess energy transporting more than 50% of annual load	**2**
	(2)	**(4)**	**(6)**	**(8)**	
3 Degree of Channel Incision (BHR)	1.00 – 1.10	1.11 – 1.30	1.31 – 1.50	> 1.50	**6**
	(2)	**(4)**	**1.48 (6)**	**(8)**	
4 Stream Succession States	Does not indicate incision or degradation	If BHR > 1.1 and stream type has W/d between 5–10	If BHR > 1.1 and stream type has W/d less than 5	(B→G), (C→G), (E→G), (D→G), (A→G), (E→A)	**2**
	(2)	**(4)**	**(6)**	**(8)**	
5 Confinement (MWR / MWR_{ref})	0.80 – 1.00	0.30 – 0.79	0.10 – 0.29	< 0.10	**1**
	0.89 (1)	**(2)**	**(3)**	**(4)**	
				Total Points	**13**
	Vertical Stability Category Point Range for Channel Incision and Degradation				
Vertical Stability for Channel Incision/ Degradation (use total points and check ✓ stability rating)	***Not Incised*** **< 12** ☐	***Slightly Incised*** **12 – 18** ☑	***Moderately Incised*** **19 – 27** ☐	***Degradation*** **> 27** ☐	

5.4.15 Channel Enlargement

Channel enlargement is assessed based on stream succession stage shifts and potential lateral and vertical instability. Channel enlargement on the North Platte through Saratoga adds to the land loss and sediment supply increase from accelerated streambank erosion, lateral instability, channel deposition, and the high width/depth ratio (**Table 24**).

Table 24. The channel enlargement prediction summary for the North Platte River through Saratoga.

Channel Enlargement Prediction					
Stream: **North Platte River**			Stream Type: **C3**		
Location: **Existing Condition**			Valley Type: **U-AL-FD**		
Observers: **BR & MG**			Date: **6/19/2014**		
Channel Enlargement Prediction Criteria (choose one stability category for each criterion 1–4)	**Channel Enlargement Prediction Categories**				**Selected Points (from each row)**
	No Increase	***Slight Increase***	***Moderate Increase***	***Extensive***	
1 **Stream Succession Stage Shifts**	Stream Type at Potential, (C→E), (F_b→B), (G→B), (F→B_c), (F→C), (D→C)	(B→High W/d B), **(C→High W/d C)**, (E→C)	(G→F), (F→D)	(C→D), (A→G), (B→G), (D→G), (C→G), (E→G), (E→A), (C→F)	4
	(2)	**(4)**	**(6)**	**(8)**	
2 **Lateral Stability**	*Stable*	*Moderately Unstable*	*Unstable*	*Highly Unstable*	8
	(2)	**(4)**	**(6)**	**(8)**	
3 **Vertical Stability Excess Deposition and Aggradation**	*No Deposition*	*Moderate Deposition*	*Excess Deposition*	*Aggradation*	8
	(2)	**(4)**	**(6)**	**(8)**	
4 **Vertical Stability Channel Incision and Degradation**	*Not Incised*	*Slightly Incised*	*Moderately Incised*	*Degradation*	4
	(2)	**(4)**	**(6)**	**(8)**	
				Total Points	24
	Category Point Range				
Channel Enlargement Prediction (use total points and check ✓ stability rating)	***No Increase*** **< 11** ☐	***Slight Increase*** **11 – 16** ☐	***Moderate Increase*** **17 – 24** ☑	***Extensive*** **> 24** ☐	

5.4.16 Overall Sediment Supply

The overall sediment supply rating is used to summarize the overall stability summary, potential impairment, and associated channel source sediment supply. The sediment supply rating for the North Platte assessment reach is *High* (**Table 25**). Reduced sediment supply must be a goal of the proposed conceptual design to offset the impairments and adverse consequence of instability. Sediment supply reduction of the existing in-channel storage (bars) and streambank erosion will be addressed in the conceptual restoration design plan.

Table 25. The overall sediment supply rating determined from individual stability rating categories for the North Platte River through Saratoga.

Overall Sediment Supply Prediction			
Stream: **North Platte River**		Stream Type: **C3**	
Location: **Existing Condition**		Valley Type: **U-AL-FD**	
Observers: **BR & MG**		Date: **6/19/2014**	
Overall Sediment Supply Prediction Criteria (choose corresponding points for each criterion 1–5)	**Stability Rating**	**Points**	**Selected Points**
1 Lateral Stability	***Stable***	**1**	**4**
	Mod. Unstable	**2**	
	Unstable	**3**	
	Highly Unstable	**4**	
2 Vertical Stability Excess Deposition or Aggradation	***No Deposition***	**1**	**4**
	Mod. Deposition	**2**	
	Excess Deposition	**3**	
	Aggradation	**4**	
3 Vertical Stability Channel Incision or Degradation	***Not Incised***	**1**	**2**
	Slightly Incised	**2**	
	Mod. Incised	**3**	
	Degradation	**4**	
4 Channel Enlargement Prediction	***No Increase***	**1**	**3**
	Slight Increase	**2**	
	Mod. Increase	**3**	
	Extensive	**4**	
5 Pfankuch Channel Stability	***Good: Stable***	**1**	**2**
	Fair: Mod. Unstable	**2**	
	Poor: Unstable	**4**	
		Total Points	**15**
	Category Point Range		
Overall Sediment Supply Rating (use total points and check ✓ stability rating)	***Low*** **< 6** ☐	***Moderate*** **6 – 10** ☐	***High*** **11 – 15** ☑	***Very High*** **> 15** ☐

5.4.17 Summary of Stability Conditions

Table 26 summarizes the key stability variables and highlights those impairments that may need to be addressed in the conceptual design. The ratings will direct the practitioner to obtain the specific values necessary to offset the impairments in the design phase. For the North Platte River, the high sediment supply from bank erosion coupled with the inability to transport the sediment load and the larger particle sizes needs to be corrected. A major channel re-shaping is needed to reduce the extremely high width/depth ratios, which will increase sediment transport capacity and competence, and will also help increase mean velocity. The streambank erosion also needs to be reduced by installing in-stream structures and re-establishing a cottonwood/willow community to provide long-term stability and biological function.

Table 26. A summary of the stability condition categories for the North Platte River through Saratoga.

Summary of Stability Conditions																
Stream:	North Platte River								Location: Existing Condition							
Observers:	BR & MG				Date: 6/19/2014				Stream Type: C3				Valley Type: U-AL-FD			
Channel Dimension	Bankfull Mean Depth (ft):	4.15	Bankfull Width (ft):	289.82	Cross-Sectional Area (ft^2):	1202	Width/Depth Ratio:	69.84	Entrenchment Ratio:	21.74						
Channel Pattern	Mean:	λ/W_{bkf}:	11.146	L_m/W_{bkf}:	13.2	R_c/W_{bkf}:	2.7	MWR:	4.2	Sinuosity:	1.17					
	Range:		5.8-15.7		7.8-16.6		0.67-8.1		3.0-5.3							
Streamflow	Bankfull Mean Velocity ($\bar{u}_{bkf}$) (ft/sec):	4.33	Bankfull Discharge (Q_{bkf}):	5200	Estimation Method:	USGS Gage Station	Drainage Area (mi^2):	2840								
River Profile & Bed Features	Check: ☑ Riffle/Pool	☐ Step/Pool	☐ Plane Bed	☐ Convergence/Divergence	☐ Dunes/Antidunes/Smooth Bed											
	Bankfull Max Depth (ft):	Riffle: 4.51	Pool: 8.64	Depth Ratio (max to mean):	Riffle: 1.2	Pool: 2.3	Pool-to-Pool Spacing:	Ratio: 6.6	Slope: Valley:	0.0026	Water Surface:	0.00218				
Level III Stream Stability Indices	Riparian Vegetation	Current Composition/Density: C.Wood/Willow/Bunch G./Forb	Potential Composition/Density: C.Wood/Willow/Rhiz. Grasses	Remarks: Condition, Vigor & Usage of Existing Reach: Clearing, grazing, and urban development												
	Flow Regime:	P1/P7	Stream Size & Order:	S-10(6)	Meander Patterns:	M3, M5, M8	Depositional Patterns:	B1, B3, B5, B7	Debris/Channel Blockages:	D1						
	Degree of Incision (Bank-Height Ratio):	1.48	Degree of Incision Stability Rating:	Mod. Incised	Modified Pfankuch Stability Rating (Numeric & Adjective Rating):	Fair (89)										
	W/d Ratio State (W/d) / (W/d_{ref}):	2.05	W/d Ratio State Stability Rating:	Highly Unstable	Degree of Confinement (MWR / MWR_{ref}):	0.89	MWR / MWR_{ref} Stability Rating:	No Departure								
Bank Erosion Summary	Length of Reach Studied (ft):	10760	Annual Streambank Erosion Rate:	3159 (tons/yr)	0.29 (tons/yr/ft)	Curve Used:	Colorado	Remarks:	High terrace banks, cleared riparian vegetation							
Sediment Capacity (POWERSED)	☐ *Sufficient Capacity*	☑ *Insufficient Capacity*	☐ *Excess Capacity*	Remarks: High width/depth ratio channel												
Entrainment/ Competence	Largest Particle from Bar Sample (mm):	177	$\tau =$	0.56	$\tau^* =$	0.029	Existing Depth:	4.1	Required Depth:	12	Existing Slope:	0.0022	Required Slope:	0.006		
Stream Succession	C3 → High W/d C3	Existing Stream State (Type):	H. W/d C3	Potential Stream State (Type):	C3											
Lateral Stability	☐ *Stable*	☐ *Mod. Unstable*	☐ *Unstable*	☑ *Highly Unstable*	Remarks: Loss of riparian and BHR of 1.5											
Vertical Stability (Aggradation)	☐ *No Deposition*	☐ *Mod. Deposition*	☐ *Ex. Deposition*	☑ *Aggradation*	Remarks: Width/depth ratio too high											
Vertical Stability (Degradation)	☐ *Not Incised*	☑ *Slightly Incised*	☐ *Mod. Incised*	☐ *Degradation*	Remarks: Incised C3 stream type											
Channel Enlargement	☐ *No Increase*	☐ *Slight Increase*	☑ *Mod. Increase*	☐ *Extensive*	Remarks: Widening											
Sediment Supply (Channel Source)	☐ *Low*	☐ *Moderate*	☑ *High*	☐ *Very High*	Remarks: Streambank erosion and bar deposition											

5.5 THE REFERENCE REACH COMPARISON

The river morphology of the existing reach is compared to a stable reference reach of the same stream type to assess departure. Due to scale differences, the form variables are converted to dimensionless form for comparison and eventual application for a natural channel design. The East Fork of the Arkansas River in Colorado was selected as the reference reach for this section of the North Platte River. Although glacial terraces bound the valley of the East Fork of the Arkansas River, the cobble-bed, meandering C3 stream type is also bounded by Holocene alluvial terraces and a floodplain. It has a moderate sinuosity of 1.5 and a range of width/depth ratios from 21–25. However, the Arkansas River is much smaller than the North Platte (375 cfs); thus the North Platte River at Northgate in Colorado near the Wyoming line that has pattern and riffle dimension data from a USGS streamgage is also used as a reference reach to supplement the Arkansas River data. The bankfull discharge at this reach of the North Platte River is 2,300 cfs and is also a C3 stream type in an unconfined alluvial valley with fluvial deposition (U-AL-FD). The reference reach data and the existing reach data are summarized in **Table 27** to compare the multiple variables.

Although the two different C3 reference reaches vary in size (375 cfs vs. 2300 cfs), the average width/depth ratio is 23, although the range is larger for the larger C3 stream type (14 to 34) (**Table 27**). The existing width/depth ratio of the North Platte study reach averaged at 84 (63 to 106), which is 3.7 times greater than the reference condition. Such a high width/depth ratio is responsible for the lower velocities, shear stress, unit stream power, and sediment transport competence and capacity in addition to fish habitat limitations. The entrenchment ratio (1.1) through Saratoga is more similar to a F3 stream type due to the levees and higher banks. The width of the flood-prone area and entrenchment ratio for the North Platte River at Northgate reference reach (1,400 ft W_{fpa} and 13.0 entrenchment ratio) is similar to the study reach (1,795 ft W_{fpa} and 6.1 entrenchment ratio), whereas the East Fork Arkansas River is more confined at 281 ft, yet the entrenchment ratio is 6.0 with a range from 4.5 to 8.5.

Other than the width/depth ratio, the ratios of the riffle inner berm features (low flow channel) between the reference reaches and study reach are surprisingly similar. Maximum pool depth ratios for the study reach are less than the reference reaches as are the point bar slopes. As the width/depth ratio decreases and point bar slope increases, pool depth increases with a higher probability of higher sediment transport to prevent future pool filling.

Runs, similar to the riffles, for the study reach have much higher width/depth ratios than the reference reach (109 compared to 25). The glide maximum depth ratios are troublesome on the study reach with values from 1.4 to 1.6 compared to the 1.1–1.2 values of the reference condition. The deeper the maximum depth of the glides, the steeper the pools and the flatter the riffles (slope reversal) immediately below the glide feature will be. This problem in the cross-sections will need to be corrected in the design. The inner berm glide data for the study reach is quite similar to reference.

Stream pattern ratios are within the range of the reference condition, which is important since it will be difficult to materially change the pattern variables through Saratoga due to the existing lateral constraints. The sinuosity for the upper North Platte River reference is 1.2 compared to 1.17 for the study reach (**Table 27**). The range of the meander width ratios of the study reach is similar to both of the reference reaches. Due to existing lateral constraints there is minimal

opportunity to change belt width and the design may need to decrease the existing belt width to allow for the construction of a bankfull bench to decrease bank height ratio. The radius of curvature ratio of the study reach (0.8) is much lower than that of the reference reaches (3.4 and 4.4) (Table 27). The radius of curvature for a bend in the study reach cannot be stable with that tight of a radius and must be increased to match the average reference reach ratios. The riffle length ratio of 0.5 for existing condition is too short and will need to be lengthened to match the reference riffle length ratios (1.7–2.5) (**Table 27**).

The ratios for the study reach of maximum riffle depth to mean riffle depth of 1.0–1.4 values from the longitudinal profile (**Table 27**) are very low and should be closer to the ranges shown for the reference reach of 1.6 to 1.8. These larger ratios will help better define an inner berm (low flow channel), which will help provide better fish habitat of instream cover (depth increase) and improve sediment transport capacity. Certain constraints of buried utilities must be identified to determine if the required depths are possible at select reaches containing utility crossings (sewer and water lines). Slope ratios for the study reach appear to be fairly close to reference conditions except for the 0.5 slope ratio of a riffle. This backwatered riffle will need to be steepened to meet the reference ratios of 1.3 to 2.1 (**Table 27**).

The application of the dimensionless ratios involving multiple variables is key to designing a stable, functioning stream channel utilizing reference reach data to determine the extent of departure and potential requirements for design. This assessment will provide the basis for the next step, which is the development of the natural channel design as part of the conceptual restoration plan.

Table 27(a). Summary of existing reach and reference reach data (page 1 of 8).

Existing Reach Stream & Location: North Platte River through Saratoga, WY						
Reference Reach Stream & Location: EF Arkansas nr Leadville/N. Platte at North Gate, CO						
Entry Number & Variable			**Existing Reach**		**Reference Reach**	
	1	Valley Type	**U-AL-FD**		**C-GL-GT, U-AL-FD**	
	2	Valley Width (W_{val})	**2400-6300**		**290-600/1,400**	
	3	Stream Type	**C3**		**C3**	
	4	Drainage Area, mi^2 (DA)	**2840**		**49.9/1,431**	
	5	Bankfull Discharge, cfs (Q_{bkf})	**5200**		**375/2,300**	
Riffle Dimensions	**6**	Riffle Width, ft (W_{bkf})	*Mean:*	**305.0**	*Mean:*	**38.8/118**
			Min:	**272.2**	*Min:*	**37.8/98**
			Max:	**372.7**	*Max:*	**39.9/138**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:*	**3.87**	*Mean:*	**1.70/5.2**
			Min:	**3.51**	*Min:*	**1.51/4.0**
			Max:	**4.27**	*Max:*	**1.88/6.2**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:*	**79.6**	*Mean:*	**23/25**
			Min:	**63.7**	*Min:*	**21.2/14**
			Max:	**106.2**	*Max:*	**25.1/34**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:*	**1173.7**	*Mean:*	**66.0/566**
			Min:	**1075.3**	*Min:*	**57.0**
			Max:	**1306.8**	*Max:*	**75.1**
	10	Riffle Maximum Depth (d_{max})	*Mean:*	**6.47**	*Mean:*	**2.79**
			Min:	**4.95**	*Min:*	**2.65**
			Max:	**7.15**	*Max:*	**2.95**
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:*	**1.681**	*Mean:*	**1.686**
			Min:	**1.320**	*Min:*	**1.569**
			Max:	**1.927**	*Max:*	**1.834**
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:*	**1983.5**	*Mean:*	**281/1400**
			Min:	**324.0**	*Min:*	**220.0**
			Max:	**6300.0**	*Max:*	**320.0**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:*	**6.8**	*Mean:*	**7.3/13**
			Min:	**1.1**	*Min:*	**5.5**
			Max:	**21.7**	*Max:*	**8.5**
Riffle Inner Berm Dimensions	**14**	Riffle Inner Berm Width, ft (W_{ib})	*Mean:*	**173.7**	*Mean:*	**21.3**
			Min:	**87.2**	*Min:*	**18.3**
			Max:	**239.5**	*Max:*	**23.3**
	15	Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:*	**0.580**	*Mean:*	**0.552**
			Min:	**0.294**	*Min:*	**0.485**
			Max:	**0.860**	*Max:*	**0.586**
	16	Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:*	**1.35**	*Mean:*	**0.66**
			Min:	**0.86**	*Min:*	**0.51**
			Max:	**1.69**	*Max:*	**0.79**
	17	Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:*	**0.352**	*Mean:*	**0.394**
			Min:	**0.238**	*Min:*	**0.320**
			Max:	**0.480**	*Max:*	**0.444**
	18	Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:*	**131.2**	*Mean:*	**33.6**
			Min:	**72.2**	*Min:*	**27.4**
			Max:	**201.0**	*Max:*	**43.6**
	19	Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:*	**237.8**	*Mean:*	**14.0**
			Min:	**75.4**	*Min:*	**11.4**
			Max:	**366.1**	*Max:*	**18.4**
	20	Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:*	**0.201**	*Mean:*	**0.216**
			Min:	**0.070**	*Min:*	**0.187**
			Max:	**0.282**	*Max:*	**0.245**

Table 27(b). Summary of existing reach and reference reach data (page 2 of 8).

Entry Number & Variable			Existing Reach		Reference Reach	
Pool Dimensions	21	Pool Width, ft (W_{bkfp})	*Mean:*	**245.9**	*Mean:*	**35.8**
			Min:	**186.3**	*Min:*	**31.5**
			Max:	**417.5**	*Max:*	**40.0**
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:*	**0.816**	*Mean:*	**0.897**
			Min:	**0.618**	*Min:*	**0.790**
			Max:	**1.385**	*Max:*	**1.004**
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:*	**4.82**	*Mean:*	**2.32**
			Min:	**3.86**	*Min:*	**2.27**
			Max:	**5.86**	*Max:*	**2.37**
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:*	**1.303**	*Mean:*	**1.234**
			Min:	**1.043**	*Min:*	**1.207**
			Max:	**1.584**	*Max:*	**1.261**
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:*	**51.0**	*Mean:*	**15.4**
			Min:	**31.8**	*Min:*	**13.3**
			Max:	**108.2**	*Max:*	**17.6**
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:*	**1146.1**	*Mean:*	**83.2**
			Min:	**846.3**	*Min:*	**71.6**
			Max:	**1612.2**	*Max:*	**94.7**
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:*	**1.039**	*Mean:*	**1.107**
			Min:	**0.767**	*Min:*	**0.954**
			Max:	**1.461**	*Max:*	**1.261**
	28	Pool Maximum Depth (d_{maxp})	*Mean:*	**7.57**	*Mean:*	**4.90**
			Min:	**5.53**	*Min:*	**4.52**
			Max:	**8.68**	*Max:*	**5.27**
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:*	**2.046**	*Mean:*	**2.606**
			Min:	**1.495**	*Min:*	**2.404**
			Max:	**2.346**	*Max:*	**2.803**
	30	Point Bar Slope (S_{pb})	*Mean:*	**0.008**	*Mean:*	**33.300**
			Min:	**0.040**	*Min:*	**28.600**
			Max:	**0.110**	*Max:*	**38.000**
Pool Inner Berm Dimensions	31	Pool Inner Berm Width, ft (W_{ibp})	*Mean:*	**181.8**	*Mean:*	**16.9**
			Min:	**135.3**	*Min:*	**15.1**
			Max:	**249.4**	*Max:*	**18.8**
	32	Pool Inner Berm Width to Pool Width (W_{ibp}/W_{bkfp})	*Mean:*	**0.752**	*Mean:*	**0.475**
			Min:	**0.546**	*Min:*	**0.470**
			Max:	**0.931**	*Max:*	**0.480**
	33	Pool Inner Berm Mean Depth, ft (d_{ibp})	*Mean:*	**2.51**	*Mean:*	**1.89**
			Min:	**1.50**	*Min:*	**1.68**
			Max:	**4.00**	*Max:*	**2.09**
	34	Pool Inner Berm Mean Depth to Pool Mean Depth (d_{ibp}/d_{bkfp})	*Mean:*	**0.528**	*Mean:*	**0.815**
			Min:	**0.299**	*Min:*	**0.709**
			Max:	**0.881**	*Max:*	**0.921**
	35	Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})	*Mean:*	**87.4**	*Mean:*	**9.2**
			Min:	**33.9**	*Min:*	**7.2**
			Max:	**166.3**	*Max:*	**11.2**
	36	Pool Inner Berm Cross-Sectional Area (A_{ibp})	*Mean:*	**427.4**	*Mean:*	**31.6**
			Min:	**242.5**	*Min:*	**31.6**
			Max:	**541.0**	*Max:*	**31.6**
	37	Pool Inner Berm Cross-Sectional Area to Pool Cross-Sectional Area (A_{ibp}/A_{bkfp})	*Mean:*	**0.387**	*Mean:*	**0.387**
			Min:	**0.215**	*Min:*	**0.333**
			Max:	**0.639**	*Max:*	**0.441**

Table 27(c). Summary of existing reach and reference reach data (page 3 of 8).

	Entry Number & Variable		Existing Reach		Reference Reach	
Run Dimensions	38	Run Width, ft (W_{bkfr})	*Mean:*	**286.6**	*Mean:*	**40.5**
			Min:	**225.6**	*Min:*	
			Max:	**347.6**	*Max:*	
	39	Run Width to Riffle Width (W_{bkfr}/W_{bkf})	*Mean:*	**0.951**	*Mean:*	**1.015**
			Min:	**0.748**	*Min:*	
			Max:	**1.153**	*Max:*	
	40	Run Mean Depth, ft (d_{bkfr})	*Mean:*	**4.06**	*Mean:*	**1.82**
			Min:	**3.24**	*Min:*	
			Max:	**4.87**	*Max:*	
	41	Run Mean Depth to Riffle Mean Depth (d_{bkfr}/d_{bkf})	*Mean:*	**1.097**	*Mean:*	**0.968**
			Min:	**0.876**	*Min:*	
			Max:	**1.316**	*Max:*	
	42	Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})	*Mean:*	**76.8**	*Mean:*	**22.2**
			Min:	**46.3**	*Min:*	
			Max:	**107.3**	*Max:*	
	43	Run Cross-Sectional Area, ft^2 (A_{bkfr})	*Mean:*	**1112.6**	*Mean:*	**73.8**
			Min:	**1099.4**	*Min:*	
			Max:	**1125.8**	*Max:*	
	44	Run Area to Riffle Area (A_{bkfr}/A_{bkf})	*Mean:*	**1.008**	*Mean:*	**0.982**
			Min:	**0.996**	*Min:*	
			Max:	**1.020**	*Max:*	
	45	Run Maximum Depth (d_{maxr})	*Mean:*	**6.7**	*Mean:*	**3.39**
			Min:	**5.7**	*Min:*	
			Max:	**7.8**	*Max:*	
	46	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:*	**1.819**	*Mean:*	**1.803**
			Min:	**1.532**	*Min:*	
			Max:	**2.103**	*Max:*	
Glide Dimensions	47	Glide Width, ft (W_{bkfg})	*Mean:*	**347.8**	*Mean:*	**42.7**
			Min:	**309.5**	*Min:*	**39.3**
			Max:	**386.1**	*Max:*	**46.0**
	48	Glide Width to Riffle Width (W_{bkfg}/W_{bkf})	*Mean:*	**1.154**	*Mean:*	**1.070**
			Min:	**1.027**	*Min:*	**0.986**
			Max:	**1.281**	*Max:*	**1.154**
	49	Glide Mean Depth, ft (d_{bkfg})	*Mean:*	**3.32**	*Mean:*	**1.68**
			Min:	**2.79**	*Min:*	**1.52**
			Max:	**3.84**	*Max:*	**1.84**
	50	Glide Mean Depth to Riffle Mean Depth (d_{bkfg}/d_{bkf})	*Mean:*	**0.897**	*Mean:*	**0.894**
			Min:	**0.754**	*Min:*	**0.809**
			Max:	**1.038**	*Max:*	**0.979**
	51	Glide Width/Depth Ratio (W_{bkfg}/d_{bkfg})	*Mean:*	**109.5**	*Mean:*	**25.4**
			Min:	**80.6**	*Min:*	**25.0**
			Max:	**138.4**	*Max:*	**25.9**
	52	Glide Cross-Sectional Area, ft^2 (A_{bkfg})	*Mean:*	**1132.4**	*Mean:*	**72.2**
			Min:	**1077.5**	*Min:*	**59.6**
			Max:	**1187.3**	*Max:*	**84.8**
	53	Glide Area to Riffle Area (A_{bkfg}/A_{bkf})	*Mean:*	**1.026**	*Mean:*	**0.961**
			Min:	**0.977**	*Min:*	**0.794**
			Max:	**1.076**	*Max:*	**1.129**
	54	Glide Maximum Depth (d_{maxg})	*Mean:*	**5.69**	*Mean:*	**2.27**
			Min:	**5.39**	*Min:*	**2.14**
			Max:	**5.98**	*Max:*	**2.40**
	55	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:*	**1.538**	*Mean:*	**1.207**
			Min:	**1.457**	*Min:*	**1.138**
			Max:	**1.616**	*Max:*	**1.277**

Table 27(d). Summary of existing reach and reference reach data (page 4 of 8).

Entry Number & Variable			Existing Reach		Reference Reach	
Glide Inner Berm Dimensions	56	Glide Inner Berm Width, ft (W_{ibg})	*Mean:*	**240.6**	*Mean:*	**24.7**
			Min:	**202.7**	*Min:*	**20.8**
			Max:	**278.6**	*Max:*	**28.6**
	57	Glide Inner Berm Width to Glide Width (W_{ibg}/W_{bkfg})	*Mean:*	**0.713**	*Mean:*	**0.575**
			Min:	**0.525**	*Min:*	**0.528**
			Max:	**0.900**	*Max:*	**0.622**
	58	Glide Inner Berm Mean Depth, ft (d_{ibg})	*Mean:*	**0.92**	*Mean:*	**0.43**
			Min:	**0.88**	*Min:*	**0.34**
			Max:	**0.96**	*Max:*	**0.52**
	59	Glide Inner Berm Mean Depth to Glide Mean Depth (d_{ibg}/d_{bkfg})	*Mean:*	**0.283**	*Mean:*	**0.265**
			Min:	**0.251**	*Min:*	**0.185**
			Max:	**0.315**	*Max:*	**0.345**
	60	Glide Inner Berm Width/Depth Ratio (W_{ibg}/d_{ibg})	*Mean:*	**259.7**	*Mean:*	**61.9**
			Min:	**230.4**	*Min:*	**39.6**
			Max:	**289.0**	*Max:*	**84.2**
	61	Glide Inner Berm Cross-Sectional Area (A_{ibg})	*Mean:*	**223.4**	*Mean:*	**10.3**
			Min:	**178.3**	*Min:*	**9.7**
			Max:	**268.6**	*Max:*	**10.9**
	62	Glide Inner Berm Area to Glide Area (A_{ibg}/A_{bkfg})	*Mean:*	**0.196**	*Mean:*	**0.149**
			Min:	**0.165**	*Min:*	**0.115**
			Max:	**0.226**	*Max:*	**0.183**

Table 27(e). Summary of existing reach and reference reach data (page 5 of 8).

Entry Number & Variable			Existing Reach		Reference Reach	
Channel Pattern	63	Linear Wavelength, ft (λ)	*Mean:*	**3359.0**	*Mean:*	**304/1720**
			Min:	**1752.0**	*Min:*	**240/1560**
			Max:	**4746.0**	*Max:*	**328/1900**
	67	Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:*	**11.146**	*Mean:*	**7.6/12.5**
			Min:	**5.813**	*Min:*	**6.0/11.3**
			Max:	**15.748**	*Max:*	**8.2/13.8**
	65	Stream Meander Length, ft (L_m)	*Mean:*	**3966.0**	*Mean:*	**456/2270**
			Min:	**2353.0**	*Min:*	**359/2000**
			Max:	**5016.0**	*Max:*	**560/2600**
	66	Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:*	**13.160**	*Mean:*	**11.4/16.4**
			Min:	**7.808**	*Min:*	**9.0/14.5**
			Max:	**16.644**	*Max:*	**14.0/18.8**
	67	Belt Width, ft (W_{blt})	*Mean:*	**1256.0**	*Mean:*	**172/759**
			Min:	**905.0**	*Min:*	**80/414**
			Max:	**1606.0**	*Max:*	**348/1104**
	68	Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:*	**4.168**	*Mean:*	**4.3/5.5**
			Min:	**3.003**	*Min:*	**2.0/3.0**
			Max:	**5.329**	*Max:*	**8.7/8.0**
	69	Radius of Curvature, ft (R_c)	*Mean:*	**818.0**	*Mean:*	**136/607**
			Min:	**202.0**	*Min:*	**92/455**
			Max:	**2429.0**	*Max:*	**180/718**
	70	Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:*	**2.714**	*Mean:*	**3.4/4.4**
			Min:	**0.670**	*Min:*	**2.3/3.3**
			Max:	**8.060**	*Max:*	**4.5/5.2**
	71	Arc Length, ft (L_a)	*Mean:*	**567.0**	*Mean:*	**144/828**
			Min:	**347.0**	*Min:*	**80/552**
			Max:	**973.0**	*Max:*	**220/1104**
	72	Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:*	**1.881**	*Mean:*	**3.6/6.0**
			Min:	**1.151**	*Min:*	**2.0/4.0**
			Max:	**3.229**	*Max:*	**5.5/8.0**
	73	Riffle Length (L_r), ft	*Mean:*	**407.1**	*Mean:*	**78.56**
			Min:	**147.0**	*Min:*	**67.28**
			Max:	**1034.3**	*Max:*	**100.33**
	74	Riffle Length to Riffle Width (L_r/W_{bkf})	*Mean:*	**1.351**	*Mean:*	**1.97**
			Min:	**0.488**	*Min:*	**1.69**
			Max:	**3.432**	*Max:*	**2.52**
	75	Individual Pool Length, ft (L_p)	*Mean:*	**1573.5**	*Mean:*	**62.8**
			Min:	**983.0**	*Min:*	**53.4**
			Max:	**2633.4**	*Max:*	**74.9**
	76	Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:*	**5.221**	*Mean:*	**1.58**
			Min:	**3.262**	*Min:*	**1.34**
			Max:	**8.738**	*Max:*	**1.88**
	77	Pool-to-Pool Spacing, ft (P_s)	*Mean:*	**1983.0**	*Mean:*	**161/1135**
			Min:	**1176.0**	*Min:*	**160/1000**
			Max:	**2508.0**	*Max:*	**162/1300**
	78	Pool-to-Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:*	**6.600**	*Mean:*	**4.1/8.2**
			Min:	**4.000**	*Min:*	**4.0/7.2**
			Max:	**8.300**	*Max:*	**4.1/9.4**

Table 27(f). Summary of existing reach and reference reach data (page 6 of 8).

	Entry Number & Variable		Existing Reach	Reference Reach
Sinuosity and Slope	79	Stream Length (SL)	**10767.0**	**600/5400**
	80	Valley Length (VL)	**9203.0**	**400/4500**
	81	Valley Slope (S_{val})	**0.0026**	**0.015/0.00417**
	82	Sinuosity (k)	SL/VL: **1.17** VS/S: **1.17**	SL/VL: **1.5/1.2** VS/S: **1.5/1.2**
	83	Average Water Surface Slope (S)	**0.0022**	**0.01/0.005**
Degree of Incision	84	Low Bank Height (LBH)	*Mean:* **7.02** *Min:* **6.72** *Max:* **7.32**	*Mean:* **2.58** *Min:* **2.31** *Max:* **2.84**
	85	Maximum Bankfull Depth (d_{max}) at Same Location as Low Bank Height (LBH) Measurement	*Mean:* **5.41** *Min:* **4.95** *Max:* **5.87**	*Mean:* **2.58** *Min:* **2.31** *Max:* **2.84**
	86	Bank-Height Ratio (LBH/d_{max})	*Mean:* **1.31** *Min:* **1.14** *Max:* **1.48**	*Mean:* **1.00** *Min:* **1.00** *Max:* **1.00**
Bed Feature Max Depth Measurements and Dimensionless Ratios from Profile	87	Riffle Maximum Depth, ft (d_{max})	*Mean:* **4.51** *Min:* **3.85** *Max:* **5.20**	*Mean:* **3.26** *Min:* **3.04** *Max:* **3.39**
	88	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **1.219** *Min:* **1.041** *Max:* **1.405**	*Mean:* **1.734** *Min:* **1.617** *Max:* **1.803**
	89	Pool Maximum Depth, ft (d_{maxp})	*Mean:* **8.64** *Min:* **7.25** *Max:* **9.46**	*Mean:* **4.90** *Min:* **4.24** *Max:* **5.25**
	90	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **2.335** *Min:* **1.959** *Max:* **2.557**	*Mean:* **2.606** *Min:* **2.255** *Max:* **2.793**
	91	Run Maximum Depth, ft (d_{maxr})	*Mean:* **5.06** *Min:* **3.90** *Max:* **5.85**	*Mean:* **3.43** *Min:* **3.16** *Max:* **3.69**
	92	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **1.368** *Min:* **1.054** *Max:* **1.581**	*Mean:* **1.824** *Min:* **1.681** *Max:* **1.963**
	93	Glide Maximum Depth, ft (d_{maxg})	*Mean:* **3.09** *Min:* **2.15** *Max:* **4.80**	*Mean:* **2.46** *Min:* **2.16** *Max:* **2.77**
	94	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **0.835** *Min:* **0.581** *Max:* **1.297**	*Mean:* **1.309** *Min:* **1.149** *Max:* **1.473**
	95	Step Maximum Depth, ft (d_{maxs})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	96	Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*

Table 27(g). Summary of existing reach and reference reach data (page 7 of 8).

	Entry Number & Variable		Existing Reach	Reference Reach
Bed Feature Water Surface Facet Slopes and Dimensionless Ratios from Profile	97	Riffle Slope (water surface facet slope) (S_{rif})	*Mean:* **0.0040** *Min:* **0.0010** *Max:* **0.0050**	*Mean:* **0.0163** *Min:* **0.0133** *Max:* **0.0211**
	98	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* **1.8349** *Min:* **0.4587** *Max:* **2.2936**	*Mean:* **1.6260** *Min:* **1.3280** *Max:* **2.1140**
	99	Pool Slope (water surface facet slope) (S_p)	*Mean:* **0.0006** *Min:* **0.0002** *Max:* **0.0010**	*Mean:* **0.0010** *Min:* **0.0010** *Max:* **0.0022**
	100	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* **0.2752** *Min:* **0.0826** *Max:* **0.4771**	*Mean:* **0.1500** *Min:* **0.1000** *Max:* **0.2150**
	101	Run Slope (water surface facet slope) (S_{run})	*Mean:* **0.0160** *Min:* **0.0040** *Max:* **0.0340**	*Mean:* **0.0192** *Min:* **0.0119** *Max:* **0.0264**
	102	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:* **7.3394** *Min:* **1.8349** *Max:* **15.5963**	*Mean:* **1.9230** *Min:* **1.1870** *Max:* **2.6420**
	103	Glide Slope (water surface facet slope) (S_g)	*Mean:* **0.0009** *Min:* **0.0007** *Max:* **0.0010**	*Mean:* **0.0013** *Min:* **0.0009** *Max:* **0.0017**
	104	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:* **0.4128** *Min:* **0.3165** *Max:* **0.4771**	*Mean:* **0.1320** *Min:* **0.0920** *Max:* **0.1710**
	105	Step Slope (water surface facet slope) (S_s)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	106	Step Slope to Average Water Surface Slope (S_s/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Channel Materials	108	**Particle Size Distribution of Active Bed**		
		D_{16} (mm)		**44.5**
		D_{35} (mm)		**70.7**
		D_{50} (mm)	**128.0**	**92.7**
		D_{84} (mm)	**231.0**	**166.4**
		D_{95} (mm)		**220.2**
		D_{100} (mm)		**362.0**
	109	**Particle Size Distribution of Bar Material or Sub-pavement**		
		D_{16} (mm)	**4.2**	**17.6**
		D_{35} (mm)	**41.1**	**24.6**
		D_{50} (mm)	**77.0**	**30.3**
		D_{84} (mm)	**145.0**	**125.0**
		D_{95} (mm)	**167.0**	**145.6**
		D_{max} (mm)	**177.0**	**155.0**

Table 27(h). Summary of existing reach and reference reach data (page 8 of 8).

	Entry Number & Variable		Existing Reach	Reference Reach
Hydraulics	110	Estimated Bankfull Mean Velocity, ft/sec ($\bar{u}_{bkf}$)	4.33	5.0/4.1
Hydraulics	111	Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	5200.0	375/2300
Sediment Competence	112	Calculated bankfull shear stress value, lbs/ft^2 (τ)	0.565	1.173
Sediment Competence	113	Predicted largest moveable particle size (mm) at bankfull shear stress, (τ)	Shields: 43.0	Shields: 92.1
			Colo.: 99.8	Colo.: 171.0
Sediment Competence	114	Largest particle size to be moved (D_{max}) (mm) (see #124: Particle Size Distribution of Bar Material)	177	155.0
Sediment Competence	115	Predicted shear stress required to initiate movement of D_{max} (mm)	Shields: 2.196	Shields: 1.934
			Colo.: 1.230	Colo.: 1.027
Sediment Competence	116	Predicted mean depth required to initiate movement of D_{max} (mm), d = $\tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope)	Shields: 16.15	Shields: 3.10
			Colo.: 16.15	Colo.: 3.10
Sediment Competence	117	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth)	Shields: 0.0085	Shields: 0.0165
			Colo.: 0.0047	Colo.: 0.0088
Sediment Competence	118	Bankfull dimensionless shear stress (τ^*)	0.029	0.024
Sediment Competence	119	Required bankfull mean depth d_{bkf} (ft) using dimensionless shear stress equation: $d_{bkf} = \tau^*(\gamma_s - 1)D_{max}/S$ (Note: D_{max} in ft)	12.66	2.04
Sediment Competence	120	Required bankfull water surface slope S (ft) using dimensionless shear stress equation: $S = \tau^*(\gamma_s - 1)D_{max}/d_{bkf}$ (Note: D_{max} in ft)	0.0067	0.0109
Streambank Erosion		**Streambank Erosion**	**Existing Reach**	**Reference Reach**
Streambank Erosion	121	Stream Length Assessed (ft)	10,780	5,250
Streambank Erosion	122	Graph/Curve Used (e.g., Yellowstone or Colorado)	Colorado	Colorado
Streambank Erosion	123	Streambank Erosion (tons/yr)	3,159	41
Streambank Erosion	124	Streambank Erosion Rate (tons/yr/ft)	0.2931	0.0078

6.0 FISH HABITAT EVALUATION

A field investigation evaluating aquatic habitat was conducted by Jim Nankervis, a fisheries biologist. His report is summarized in ***APPENDIX VI***. The limitations of habitat are similar to the instability issues of the existing stream type associated with high width/depth ratios (poor instream cover) and poor overhead cover from lack of riparian vegetation throughout the reach.

7.0 LITERATURE CITED

Bartlett, A.B. (1926). The Mineral Hot Springs of Wyoming. State Geologist's Bulletin, Bulletin Number 19, the State of Wyoming Geologist's Office.

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Pfankuch, D.J. (1975). *Stream Reach Inventory and Channel Stability Evaluation* (USDAFS No. R1-75-002, GPO No. 696-260/200). Washington, DC: U.S. Government Printing Office.

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Stevens, J.G., & Bergin, M.J. (1955). Reconnaissance Investigation of Uranium Occurrences in the Saratoga Area, Carbon County, Wyoming (U.S. Department of the Interior Geological Survey, Trace Elements Investigations Report 558). Washington, DC: U.S. Government Printing Office.

APPENDIX I: CONSTRAINTS

A - 12" SEWER LINE

B - 12" WATER LINE (SEE EXHIBIT B)

C - 6" PHONE CONDUIT (SEE EXHIBIT C)

D - 12" WATER LINE

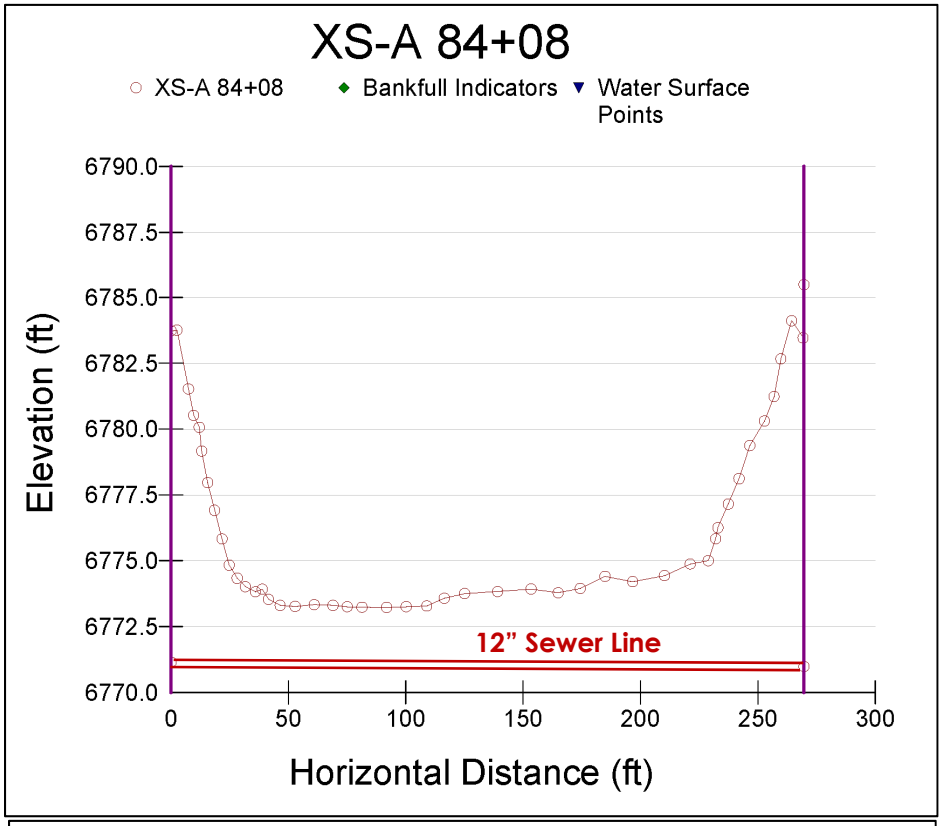
E - PEDESTRIAN BRIDGE

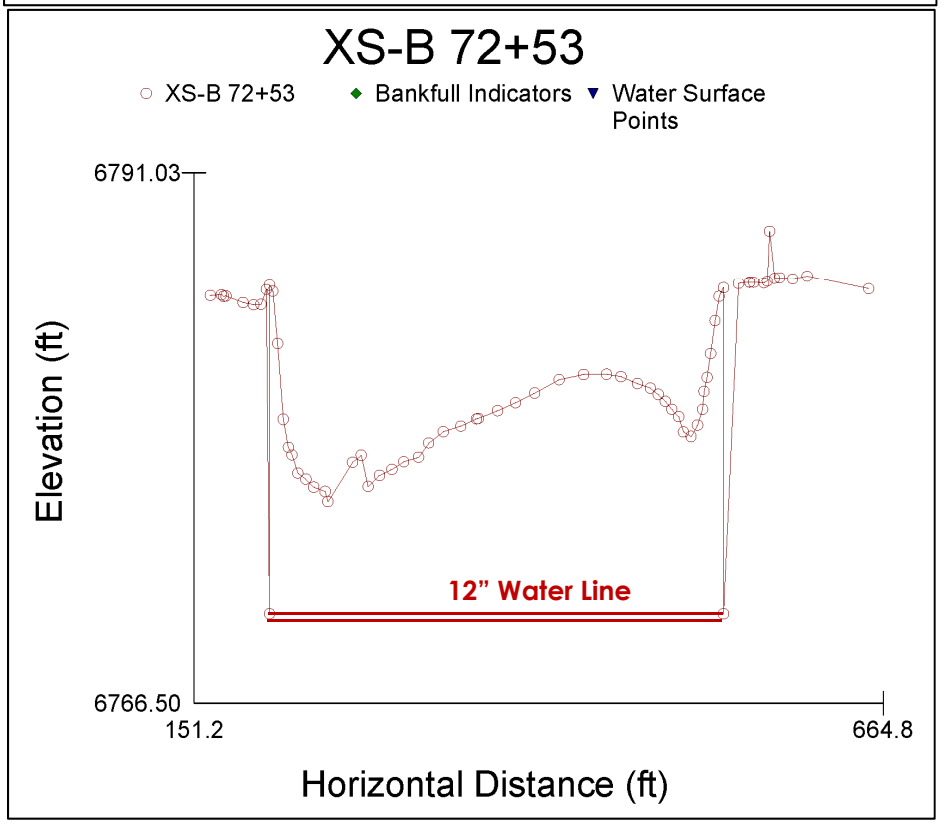
F - 10" SEWER LINE

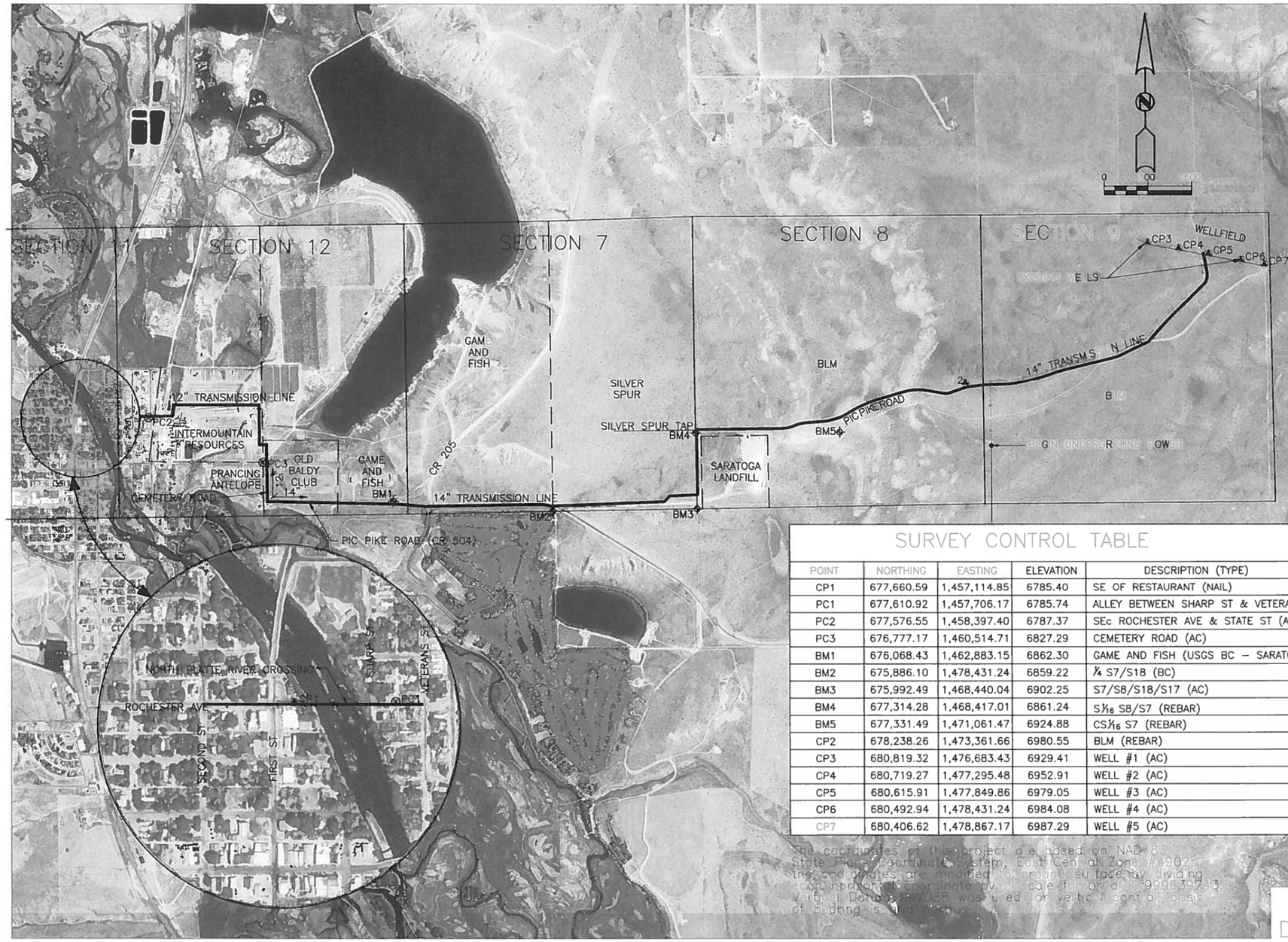
G - 6" WATER LINE (EXPOSED ON SOUTH SIDE)

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

APPENDIX I: CONSTRAINTS (CROSS-SECTIONS A & B)







SURVEY CONTROL TABLE

POINT	NORTHING	EASTING	ELEVATION	DESCRIPTION (TYPE)
CP1	677,660.59	1,457,114.85	6785.40	SE OF RESTAURANT (NAIL)
PC1	677,610.92	1,457,706.17	6785.74	ALLEY BETWEEN SHARP ST & VETERANS ST (AC)
PC2	677,576.55	1,458,397.40	6787.37	SEc ROCHESTER AVE & STATE ST (AC)
PC3	676,777.17	1,460,514.71	6827.29	CEMETERY ROAD (AC)
BM1	676,068.43	1,462,883.15	6862.30	GAME AND FISH (USGS BC – SARATOGA 2)
BM2	675,886.10	1,478,431.24	6859.22	¼ S7/S18 (BC)
BM3	675,992.49	1,468,440.04	6902.25	S7/S8/S18/S17 (AC)
BM4	677,314.28	1,468,417.01	6861.24	S 1/16 S8/S7 (REBAR)
BM5	677,331.49	1,471,061.47	6924.88	CS 1/16 S7 (REBAR)
CP2	678,238.26	1,473,361.66	6980.55	BLM (REBAR)
CP3	680,819.32	1,476,683.43	6929.41	WELL #1 (AC)
CP4	680,719.27	1,477,295.48	6952.91	WELL #2 (AC)
CP5	680,615.91	1,477,849.86	6979.05	WELL #3 (AC)
CP6	680,492.94	1,478,431.24	6984.08	WELL #4 (AC)
CP7	680,406.62	1,478,867.17	6987.29	WELL #5 (AC)

The coordinates of this project are based on NAD 83 State Plane Coordinate System, East Central Zone #4902. The coordinates are modified to ground surface by dividing each horizontal coordinate by a scale factor of 0.9996639743. Vertical Datum NAVD88 was used for vertical control, basis of bearing is true north.

REV	DATE	BY	DESCRIPTION
1	3/16/09	DF	RECORD DRAWINGS

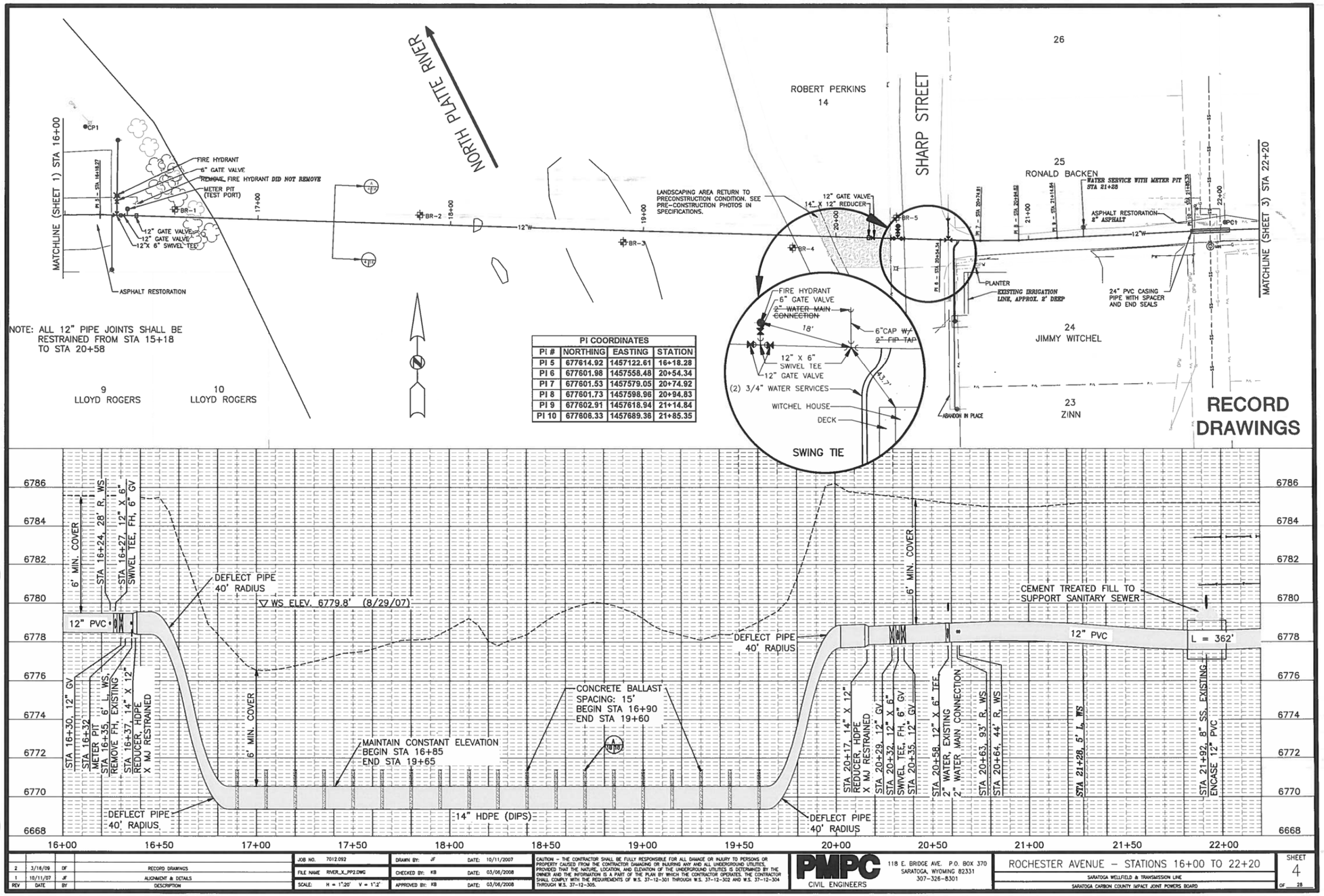
JOB NO. 7012.092 | DRAWN BY: JF | DATE: 02/19/08
FILE NAME OVERVIEW.DWG | CHECKED BY: KB | DATE: 02/19/08
SCALE: 1" = 800' | APPROVED BY: KB | DATE: 02/19/08

CAUTION – THE CONTRACTOR SHALL BE FULLY RESPONSIBLE FOR ALL DAMAGE OR INJURY TO PERSONS OR PROPERTY CAUSED FROM THE CONTRACTOR DAMAGING OR INJURING ANY AND ALL UNDERGROUND UTILITIES, PROVIDED THAT THE NATURE, LOCATION, AND ELEVATION OF THE UNDERGROUND UTILITIES IS DETERMINED BY THE OWNER AND THE INFORMATION IS A PART OF THE PLAN BY WHICH THE CONTRACTOR OPERATES. THE CONTRACTOR SHALL COMPLY WITH THE REQUIREMENTS OF W.S. 37-12-301 THROUGH W.S. 37-12-302 AND W.S. 37-12-304 THROUGH W.S. 37-12-305.

PMPC CIVIL ENGINEERS
118 E BRIDGE AVE. P.O. BOX 370
SARATOGA, WYOMING 82331
7 326-8301

OVERVIEW AND SURVEY CONTROL
SARATOGA WELLFIELD & TRANSMISSION LINE
SARATOGA CARBON COUNTY IMPACT JOINT POWERS BOARD

SHEET 2 OF 28


NORTH PLATTE RIVER
SHARP STREET
ROBERT PERKINS
14
26
25
RONALD BACKEN
24
JIMMY WITCHEL
23
ZINN
9
LLOYD ROGERS
10
LLOYD ROGERS
MATCHLINE (SHEET 1) STA 16+00
MATCHLINE (SHEET 3) STA 22+20
FIRE HYDRANT
6" GATE VALVE
REMOVE FIRE HYDRANT DID NOT REMOVE
METER PIT (TEST PORT)
12" GATE VALVE
12" GATE VALVE
12"X 6" SWIVEL TEE
ASPHALT RESTORATION
LANDSCAPING AREA RETURN TO PRECONSTRUCTION CONDITION. SEE PRE-CONSTRUCTION PHOTOS IN SPECIFICATIONS.
12" GATE VALVE
14" X 12" REDUCER
WATER SERVICE WITH METER PIT STA 21+28
ASPHALT RESTORATION 2" ASPHALT
PLANTER
EXISTING IRRIGATION LINE, APPROX. 2' DEEP
24" PVC CASING PIPE WITH SPACER AND END SEALS
ABANDON IN PLACE
NOTE: ALL 12" PIPE JOINTS SHALL BE RESTRAINED FROM STA 15+18 TO STA 20+58
FIRE HYDRANT
6" GATE VALVE
2" WATER MAIN CONNECTION
6"CAP W/ 2" FIP TAP
12" X 6" SWIVEL TEE
12" GATE VALVE
(2) 3/4" WATER SERVICES
WITCHEL HOUSE
DECK
SWING TIE
RECORD DRAWINGS
DEFLECT PIPE 40' RADIUS
WS ELEV. 6779.8' (8/29/07)
CEMENT TREATED FILL TO SUPPORT SANITARY SEWER
12" PVC
L = 362'
CONCRETE BALLAST SPACING: 15' BEGIN STA 16+90 END STA 19+60
MAINTAIN CONSTANT ELEVATION BEGIN STA 16+85 END STA 19+65
14" HDPE (DIPS)
6' MIN. COVER
STA 16+30, 12" GV
STA 16+32
METER PIT
STA 16+35, 6" L, WS
REMOVE FH, EXISTING
STA 16+37, 14" X 12" REDUCER, HDPE X MJ RESTRAINED
STA 16+24, 28' R, WS
STA 16+27, 12" X 6" SWIVEL TEE, FH, 6" GV
STA 20+17, 14" X 12" REDUCER, HDPE X MJ RESTRAINED
STA 20+29, 12" GV
STA 20+32, 12" X 6"
SWIVEL TEE, FH, 6" GV
STA 20+35, 12" GV
STA 20+58, 12" X 6" TEE
2" WATER, EXISTING
2" WATER MAIN CONNECTION
STA 20+63, 93' R, WS
STA 20+64, 44' R, WS
STA 21+28, 5' L, WS
STA 21+92, 8" SS, EXISTING
ENCASE 12" PVC
6786
6784
6782
6780
6778
6776
6774
6772
6770
6668
16+00
16+50
17+00
17+50
18+00
18+50
19+00
19+50
20+00
20+50
21+00
21+50
22+00
PI COORDINATES
PI # NORTHING EASTING STATION
PI 5 677614.92 1457122.61 16+18.28
PI 6 677601.98 1457558.48 20+54.34
PI 7 677601.53 1457579.05 20+74.92
PI 8 677601.73 1457598.96 20+94.83
PI 9 677602.91 1457618.94 21+14.84
PI 10 677606.33 1457689.36 21+85.35
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1 10/11/07 JF ALIGNMENT & DETAILS
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SCALE: H = 1"=20' V = 1"=2'
DRAWN BY: JF DATE: 10/11/2007
CHECKED BY: KB DATE: 03/06/2008
APPROVED BY: KB DATE: 03/06/2008
CAUTION - THE CONTRACTOR SHALL BE FULLY RESPONSIBLE FOR ALL DAMAGE OR INJURY TO PERSONS OR PROPERTY CAUSED FROM THE CONTRACTOR DAMAGING OR INJURING ANY AND ALL UNDERGROUND UTILITIES, PROVIDED THAT THE NATURE, LOCATION, AND ELEVATION OF THE UNDERGROUND UTILITIES IS DETERMINED BY THE OWNER AND THE INFORMATION IS A PART OF THE PLAN BY WHICH THE CONTRACTOR OPERATES. THE CONTRACTOR SHALL COMPLY WITH THE REQUIREMENTS OF W.S. 37-12-301 THROUGH W.S. 37-12-302 AND W.S. 37-12-304 THROUGH W.S. 37-12-305.
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307-326-8301
ROCHESTER AVENUE - STATIONS 16+00 TO 22+20
SARATOGA WELLFIELD & TRANSMISSION LINE
SARATOGA CARBON COUNTY IMPACT JOINT POWERS BOARD
SHEET 4 OF 28

EXHIBIT B

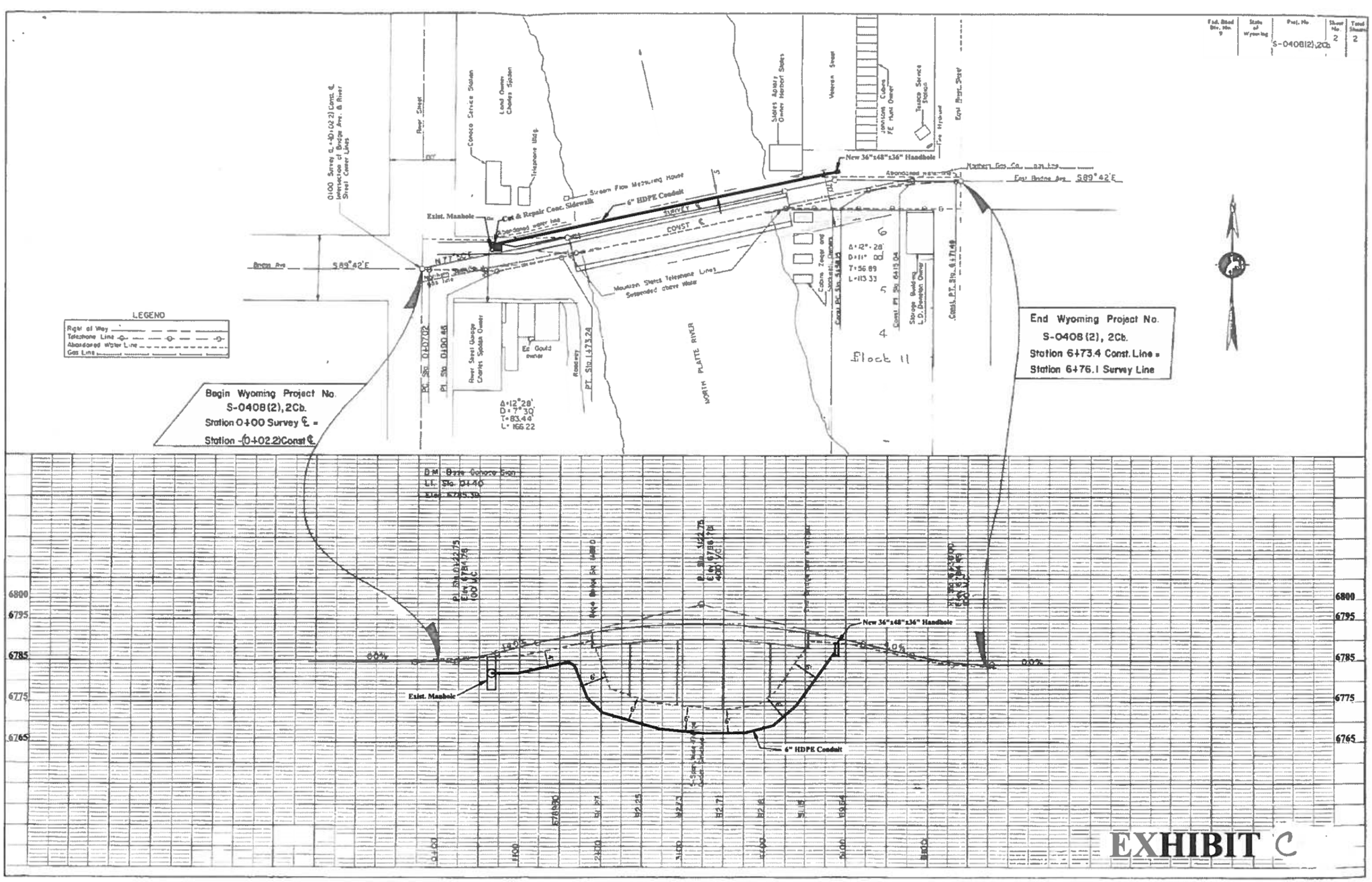
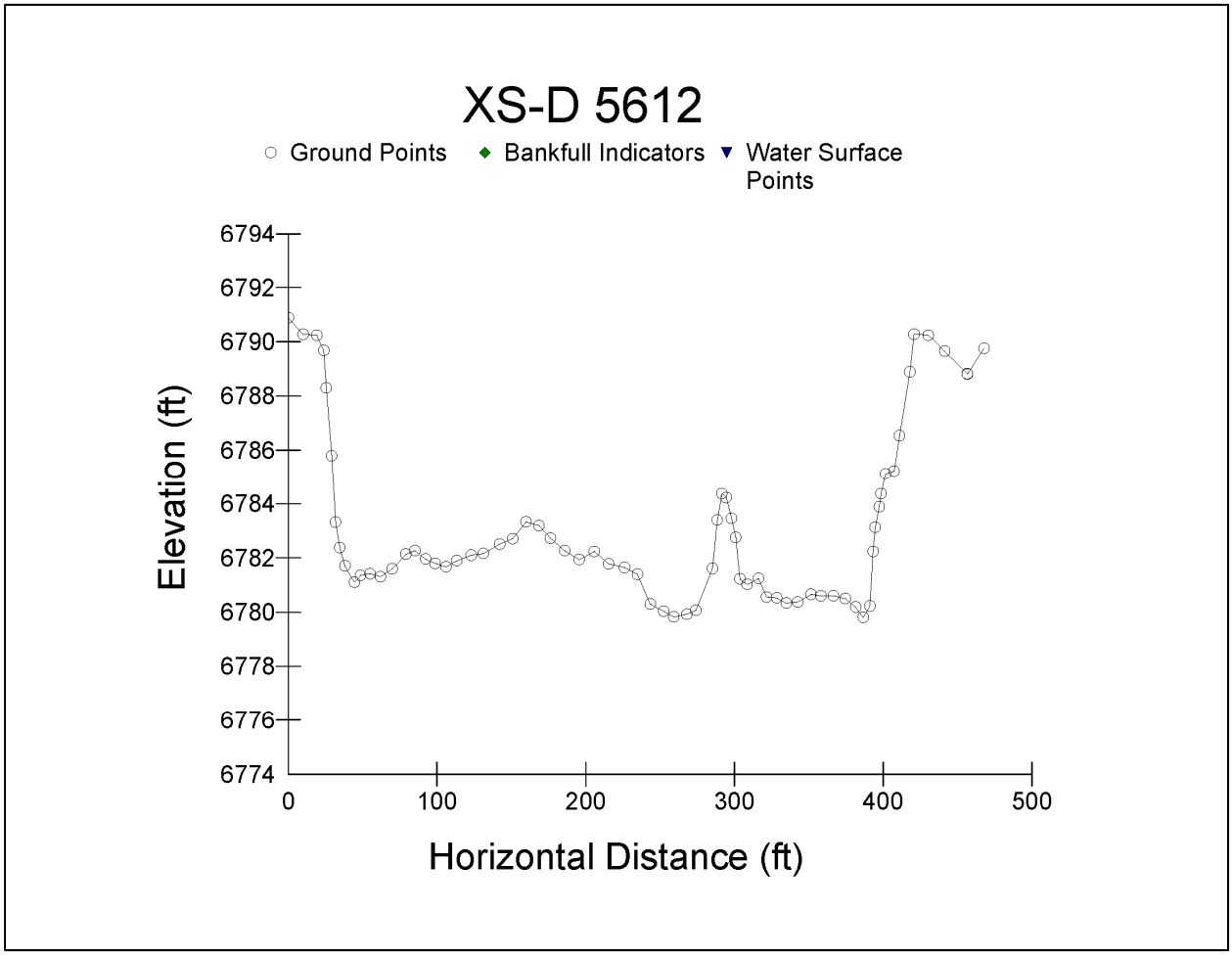

LEGEND
Right of Way
Telephone Line
Abandoned Water Line
Gas Line
Begin Wyoming Project No.
S-0408(2), 2Cb.
Station 0+00 Survey ℄ =
Station -(0+02.2)Const ℄
End Wyoming Project No.
S-0408(2), 2Cb.
Station 6+73.4 Const. Line =
Station 6+76.1 Survey Line
Exist. Manhole
New 36"x48"x36" Handhole
6" HDPE Conduit
NORTH PLATTE RIVER
Block 11
6800
6795
6785
6775
6765

EXHIBIT C

APPENDIX I: CONSTRAINTS (CROSS-SECTION D)



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SARATOGA PEDESTRIAN BRIDGE

SARATOGA, WY

TOWN OF SARATOGA

DRAWING INDEX

SHEET NO.	DESCRIPTION	REV A
T001	TITLE PAGE	12/06/2013
T002	GENERAL NOTES	12/06/2013
T003	BEARING REACTION & ANCHOR BOLT LAYOUT	12/06/2013
S101	ELEVATION & PLAN VIEW	12/06/2013
S102	CROSS SECTION	12/06/2013
S103	BEARING ELEVATIONS	12/06/2013
S104	BEARING DETAILS	12/06/2013
S105	SPLICE	12/06/2013

REV	STATUS	BY	DATE
A	ISSUE FOR APPROVAL	XYH	12/06/2013

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BIG R BRIDGE

P.O. Box 1290 • Greeley, Colorado 80632-1290
(970) 356-9600 • Fax:(970) 356-9621 • www.bigrbridge.com

150'-0" x 8'-0"
SARATOGA PEDESTRIAN BRIDGE
SARATOGA, WY
TOWN OF SARATOGA

Professional Engineer (Civil)
SEAN L. JOHNSON
8777
Date 12/6/13
WYOMING

BR09-04692

DESIGN BY ENL
DRAWN BY XYH
CHECKED BY ENL
SHEET NO. T001 OF T003

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GENERAL NOTES

1) BIG R BRIDGE IS AISC QUALITY CERTIFIED FOR SIMPLE AND MAJOR STEEL BRIDGES WITH A FRACTURE CRITICAL AND SOPHISTICATED PAINT ENDORSEMENT, AND CWB CERTIFIED TO CSA STANDARD W47.1 DIVISION 2.

2) DESIGN IS IN ACCORDANCE WITH THE "LRFD GUIDE SPECIFICATIONS FOR DESIGN OF PEDESTRIAN BRIDGES" BY AASHTO, DECEMBER 2009.

3) MATERIALS (UNLESS NOTED OTHERWISE):

a) HSS SECTIONS:	ASTM A847 WEATHERING STEEL	Fy = 50 ksi MIN.
b) STEEL SHAPES:	ASTM A588 WEATHERING STEEL	Fy = 50 ksi
c) STEEL PLATES:	ASTM A588 WEATHERING STEEL	Fy = 50 ksi
d) ANCHOR BOLTS:	ASTM F1554 GRADE 55	Fy = 55 ksi (GALV)
e) STRUCTURAL BOLTS:	ASTM A325 TYPE 3	
f) WOOD DECK:	TREATED DOUGLAS FIR (S4S) NO.2	

4) DESIGN LOADINGS:
   a) BRIDGE DEAD LOAD
   b) UNIFORM PEDESTRIAN LIVE LOAD OF 90 PSF.
   c) VEHICLE LIVE LOAD OF 8,000 LB TRUCK.
   d) WIND LOAD FROM 90 MPH WIND AT A MAX HEIGHT OF 32.8' ABOVE GRADE.

5) BRIDGE TO BE BUILT TO THE REQUIREMENTS OF AWS D1.1

6) ALL SHOP WELDING SHALL USE THE GAS METAL ARC WELDING OR FLUX CORED ARC WELDING PROCESS.

7) FINISH:
   ALL EXPOSED SURFACES OF STRUCTURAL STEEL TO BE BRUSH-OFF BLAST CLEANED IN ACCORDANCE WITH SSPC-SP7. EXPOSED SURFACES OF STEEL SHALL BE DEFINED AS THOSE SURFACES SEEN FROM THE DECK OR FROM THE OUTSIDE AND BOTTOM OF THE STRUCTURE.

8) ALL BOLTS AND NUTS SHALL BE FURNISHED IN THE AMOUNT OF 5% IN EXCESS OF THE NUMBER REQUIRED FOR EACH SIZE AND LENGTH.

9) MAINTENANCE NOTE: DO NOT APPLY DE-ICING OR DUST PROHIBITIVE CHEMICALS OR SALTS TO ANY PART OF THE BRIDGE STRUCTURE.

10) SHOP SPLICES:
   a) ALL TOP AND BOTTOM CHORD SHOP SPLICES TO BE COMPLETE PENETRATION TYPE WELDS.
   b) ALL SAFETY RAIL SHOP SPLICES TO BE SEAL WELDS LOCATED AT CENTERLINE OF VERTICAL.
   c) ALL STRINGER SHOP SPLICES TO BE SEAL WELDS LOCATED OVER CENTERLINE OF FLOOR BEAM.

11) WOOD SHALL BE ACQ TREATED OR EQUAL: TREATED TO 0.4 PCF OR REFUSAL.

BIG R BRIDGE
1-800-234-0734
bigrbridge.com
LOAD LIMIT 8000lb
SERIAL NUMBER BR09-04692
DATE OF MANUFACTURE

DATA PLATE DETAIL

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Professional Engineer (Civil) SEAN L. JOHNSON 8777 WYOMING
Date 12/6/13

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SHEET NO. T002 OF T003

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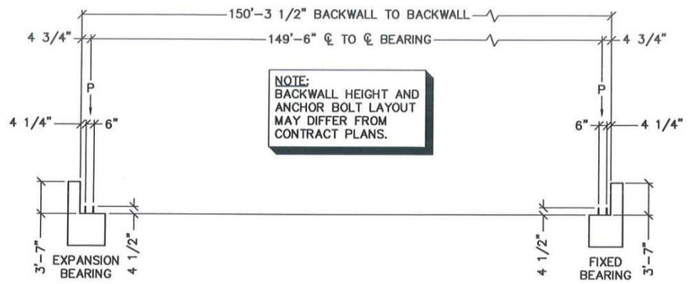
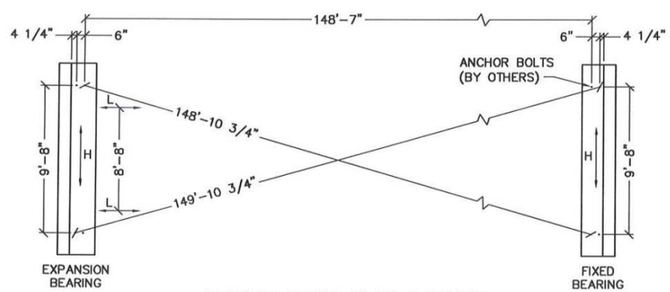


NOTE:
BACKWALL HEIGHT AND ANCHOR BOLT LAYOUT MAY DIFFER FROM CONTRACT PLANS.

ANCHOR BOLT ELEVATION LAYOUT



ANCHOR BOLT PLAN LAYOUT

BRIDGE REACTIONS	P (LBS)	H (LBS)	L (LBS)
DEAD	14,500		
LIVE (90 PSF)	27,000		
VEHICLE (8000 LB)	4,200		
WIND (90 MPH)	±13,100	24,700	
OVERTURNING (20 PSF)	−8,800		
SEISMIC		11,600	11,600
THERMAL			2,200

"P": FOUR PER BRIDGE
"H": TWO PER BRIDGE (ONE PER ABUTMENT)
"L": FOUR PER BRIDGE
LIFTING WEIGHT = 58,000 LBS

NOTE:
ANCHOR BOLTS ARE DESIGNED BY BIG R BRIDGE FOR STEEL STRENGTH IN SHEAR AND TENSION OF THE ANCHOR BOLT ONLY. ALL DESIGN CONSIDERATIONS REGARDING CONCRETE BREAKOUT STRENGTH IN SHEAR AND TENSION, PULLOUT STRENGTH, CONCRETE SIDE-FACE BLOWOUT STRENGTH, CONCRETE PRYOUT STRENGTH, EMBEDMENT DEPTH, TYPE OF ANCHORAGE OR ANY OTHER CONCRETE FAILURE MODES ARE NOT CONSIDERED AND ARE NOT THE RESPONSIBILITY OF BIG R BRIDGE. IF LARGER DIAMETER BOLTS ARE REQUIRED TO MEET ANY OF THESE REQUIREMENTS, THAT INFORMATION MUST BE PROVIDED TO BIG R BRIDGE PRIOR TO BEGINNING ANY FABRICATION ON THE BRIDGE.

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SARATOGA, WY
TOWN OF SARATOGA

Professional Engineer (Civil)
SEAN L. JOHNSON
8777
Date 12/6/13
WYOMING

BR09-04692
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SHEET NO. T003 OF T003

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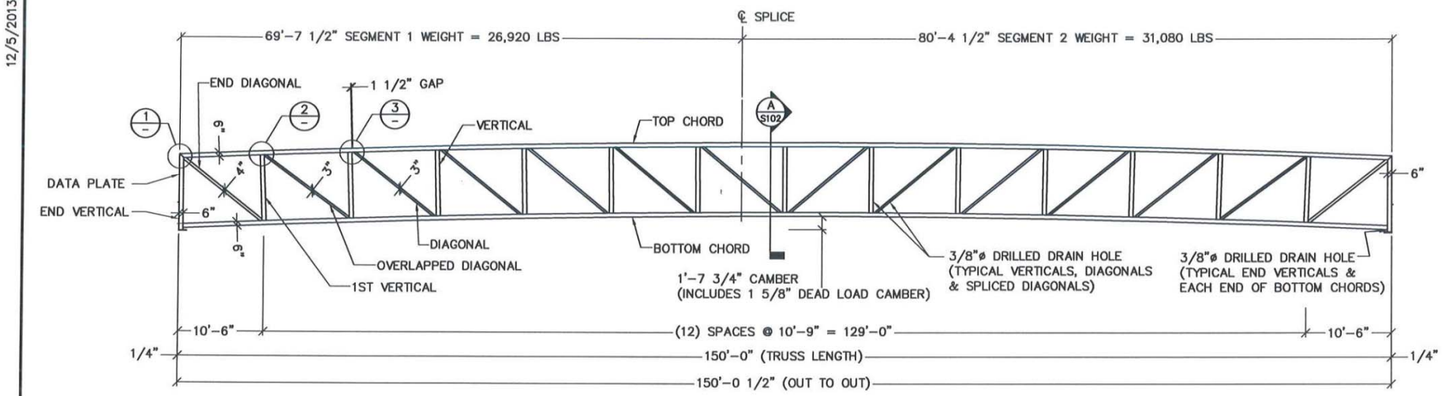
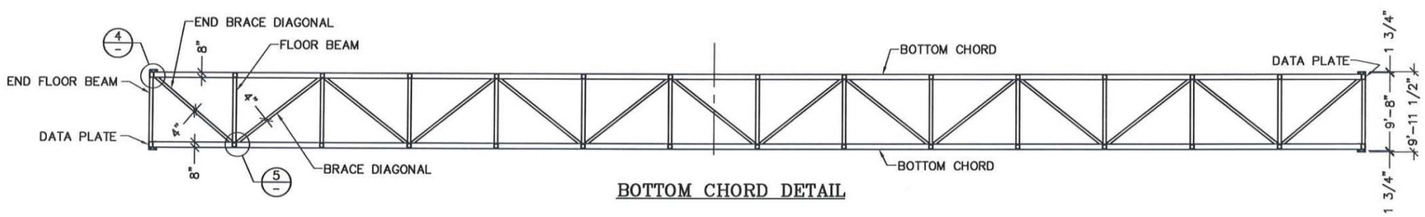
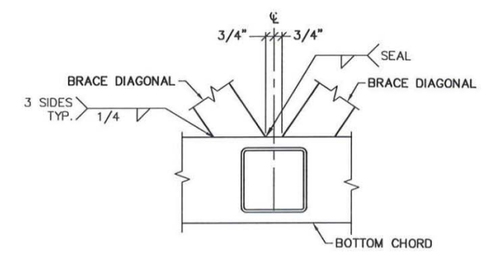


OUTSIDE ELEVATION

MEMBERS	SIZE
TOP CHORD	HSS 8x6x3/8
BOTTOM CHORD	HSS 8x6x3/8
END VERTICAL	HSS 8x6x3/8
1st VERTICAL	HSS 6x6x1/4
VERTICAL	HSS 6x6x1/4
END DIAGONAL	HSS 6x4x1/4
OVERLAPPED DIAGONAL	HSS 5x3x1/4
DIAGONAL	HSS 5x3x1/4
END BRACE DIAGONAL	HSS 4x4x1/4
BRACE DIAGONAL	HSS 4x4x1/4
END FLOOR BEAM	W 14x22
FLOOR BEAM	W 14x22
END DAM	PL 1/4"x 6"
COVER PLATE	PL 1/4"x 8"
SAFETY RAIL	L 1 1/2x1 1/2x1/8
STRINGER	HSS 4x3x1/4
BRIDGE DECKING	3x12 DF
ANCHOR BOLT (BY OTHERS)	3/4"ø (GALVANIZED)

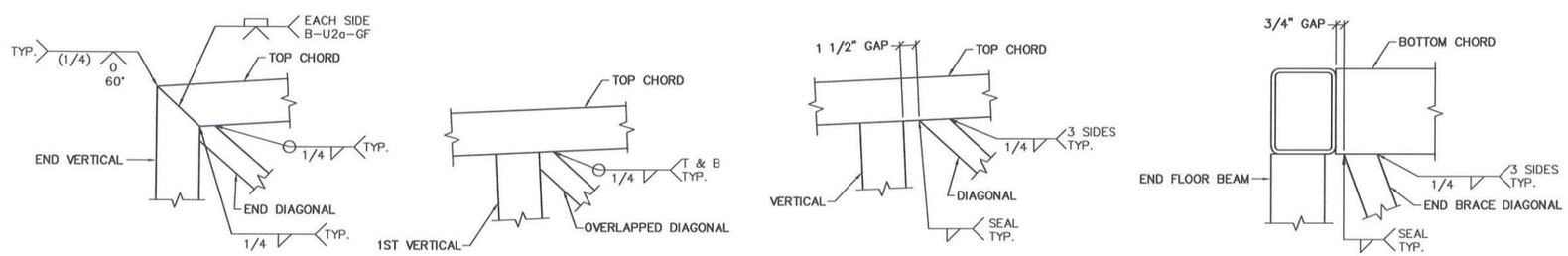


BOTTOM CHORD DETAIL



DETAIL 5

FOR CLARITY: FLOOR BEAM NOT SHOWN



DETAIL 1 DETAIL 2 DETAIL 3 DETAIL 4

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SARATOGA PEDESTRIAN BRIDGE

SARATOGA, WY

TOWN OF SARATOGA

Professional Engineer (Civil) SEAN L. JOHNSON 8777 Date 12/05/13 WYOMING

BR09-04692

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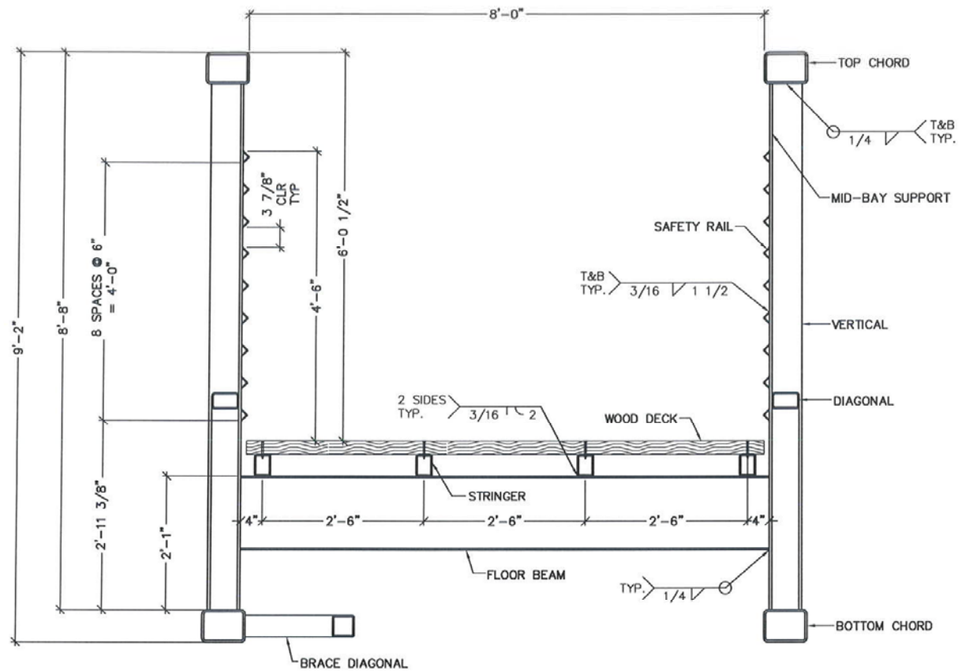
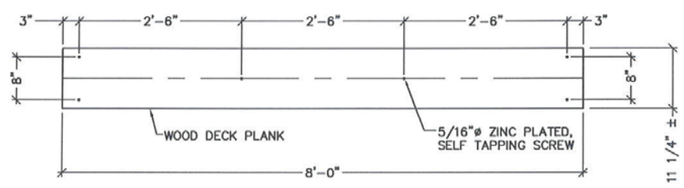


CROSS SECTION (A S101)



WOOD DECK FASTENING DETAIL

(160 PLANKS REQUIRED)

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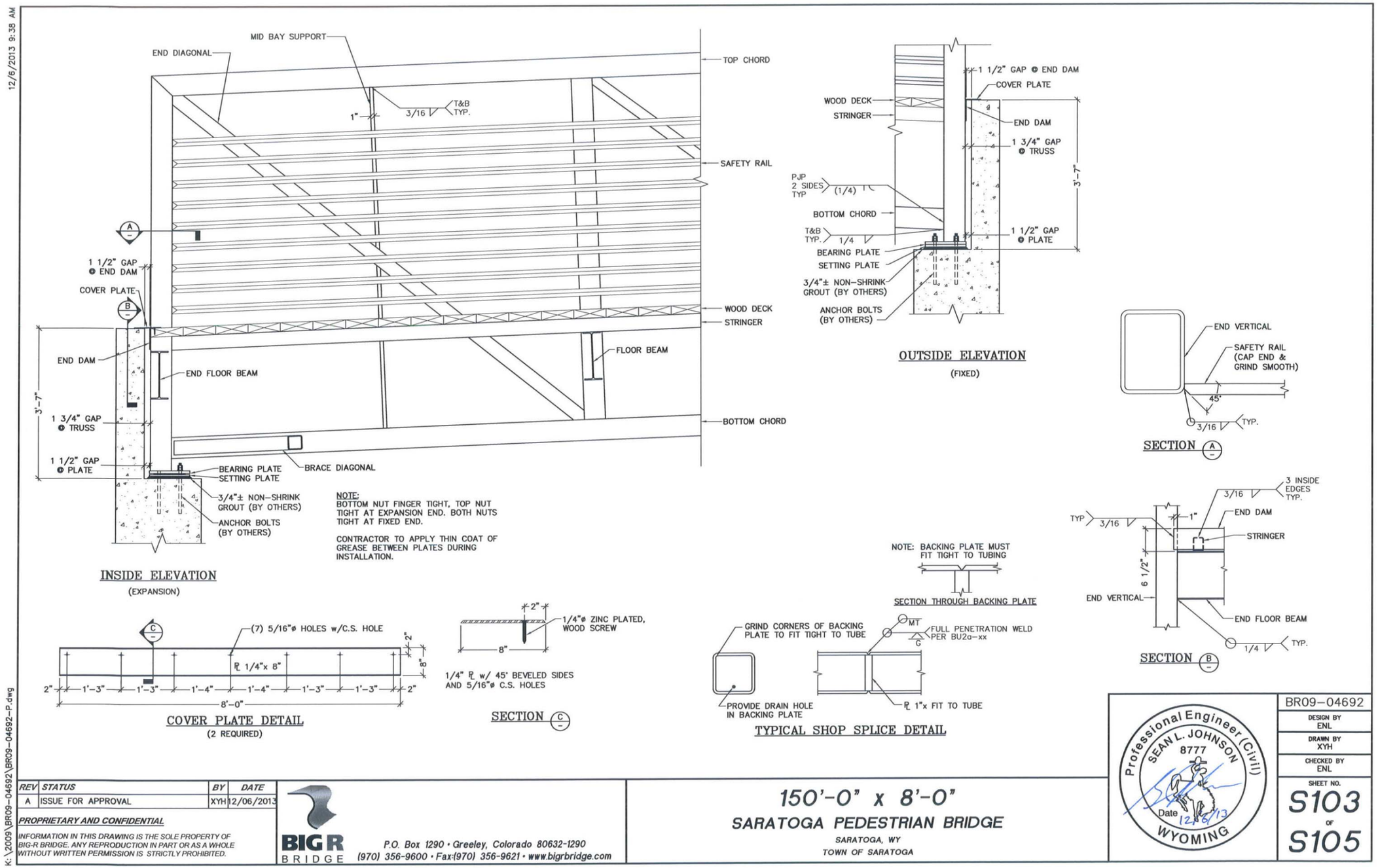
12/6/2013 9:38 AM
MID BAY SUPPORT
END DIAGONAL
TOP CHORD
1"
3/16
T&B TYP.
SAFETY RAIL
A
1 1/2" GAP @ END DAM
COVER PLATE
B
WOOD DECK
STRINGER
END DAM
END FLOOR BEAM
FLOOR BEAM
3'-7"
1 3/4" GAP @ TRUSS
BOTTOM CHORD
1 1/2" GAP @ PLATE
BEARING PLATE
SETTING PLATE
BRACE DIAGONAL
3/4"± NON-SHRINK GROUT (BY OTHERS)
ANCHOR BOLTS (BY OTHERS)
NOTE:
BOTTOM NUT FINGER TIGHT, TOP NUT TIGHT AT EXPANSION END. BOTH NUTS TIGHT AT FIXED END.
CONTRACTOR TO APPLY THIN COAT OF GREASE BETWEEN PLATES DURING INSTALLATION.
INSIDE ELEVATION
(EXPANSION)
1 1/2" GAP @ END DAM
COVER PLATE
END DAM
1 3/4" GAP @ TRUSS
PJP 2 SIDES TYP
(1/4)
BOTTOM CHORD
T&B TYP.
1/4
BEARING PLATE
SETTING PLATE
3/4"± NON-SHRINK GROUT (BY OTHERS)
ANCHOR BOLTS (BY OTHERS)
1 1/2" GAP @ PLATE
OUTSIDE ELEVATION
(FIXED)
END VERTICAL
SAFETY RAIL (CAP END & GRIND SMOOTH)
45°
3/16
TYP.
SECTION A
C
(7) 5/16"ø HOLES w/C.S. HOLE
PL 1/4"x 8"
2"
8"
1'-3"
1'-4"
8'-0"
COVER PLATE DETAIL
(2 REQUIRED)
2"
1/4"ø ZINC PLATED, WOOD SCREW
8"
1/4" PL w/ 45° BEVELED SIDES AND 5/16"ø C.S. HOLES
SECTION C
NOTE: BACKING PLATE MUST FIT TIGHT TO TUBING
SECTION THROUGH BACKING PLATE
GRIND CORNERS OF BACKING PLATE TO FIT TIGHT TO TUBE
MT
FULL PENETRATION WELD PER BU2a-xx
G
PROVIDE DRAIN HOLE IN BACKING PLATE
PL 1"x FIT TO TUBE
TYPICAL SHOP SPLICE DETAIL
3 INSIDE EDGES TYP.
TYP
3/16
1"
END DAM
STRINGER
6 1/2"
END VERTICAL
END FLOOR BEAM
1/4
TYP.
SECTION B
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A ISSUE FOR APPROVAL XYH 12/06/2013
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SHEET NO.
S103
OF
S105

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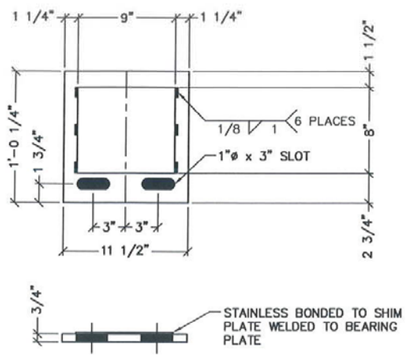
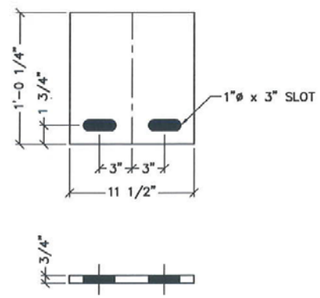


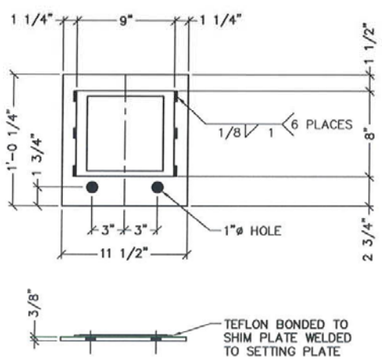
EXPANSION END BEARING PLATE

(2) REQUIRED



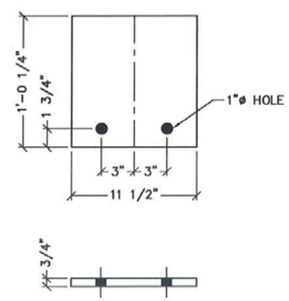
FIXED END BEARING PLATE

(2) REQUIRED



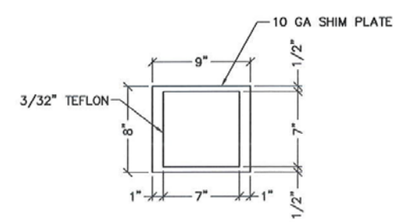
EXPANSION END SETTING PLATE

(2) REQUIRED
(SHIP LOOSE)



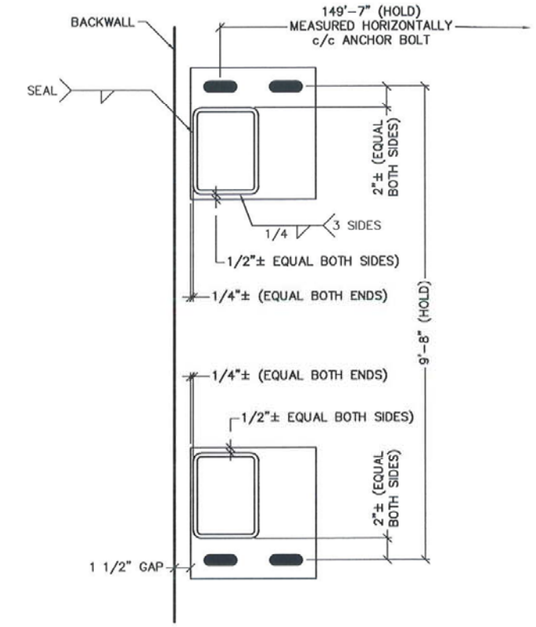
FIXED END SETTING PLATE

(2) REQUIRED
(SHIP LOOSE)



TEFLON/SHIM PLATE LAYOUT

(2) REQUIRED



PLAN SHOWING BEARING PLATE CONNECTION

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Professional Engineer (Civil)
SEAN L. JOHNSON
8777
Date 12/6/13
WYOMING

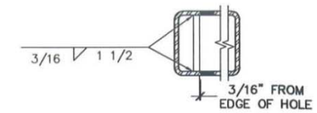
BR09-04692
DESIGN BY ENL
DRAWN BY XYH
CHECKED BY ENL
SHEET NO. S104 OF S105

12/5/2013 9:54 AM

BOLTED SPLICE NOTES:

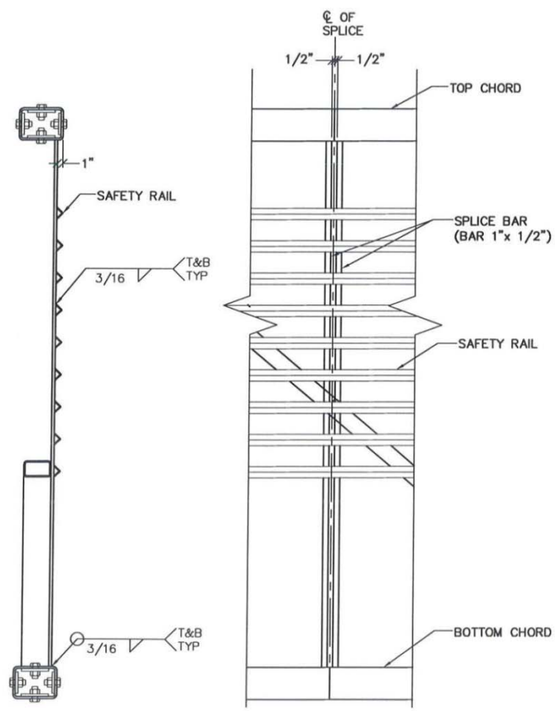
1. WASHERS ARE NOT PROVIDED. PER SECTION 11.5.6.4.4 OF AASHTO LRFD BRIDGE CONSTRUCTION SPECIFICATIONS, SECOND EDITION WITH 2009 INTERIM REVISIONS OR SECTIONS 6.1 AND 6.2 OF RCSC SPECIFICATION FOR STRUCTURAL JOINTS USING ASTM A325 OR A490 BOLTS, 2004 WASHERS ARE NOT REQUIRED.
2. ALL STRUCTURAL BOLTS TO BE INSTALLED PER THE TURN-OF-NUT INSTALLATION METHOD.
3. IF BOLTS DO NOT SMOOTHLY ENGAGE UP TO SNUG-TIGHT, THERE MAY BE AN OBSTRUCTION WITHIN THE THREADS. THE BOLT SHOULD BE REMOVED, THE THREADS ON THE BOLT AND NUT CLEANED AND RETAPPED IF NECESSARY TO ALLOW SMOOTH INSTALLATION OF THE BOLT.

MEMBERS	QTY	THICKNESS	SPLICE PLATE SIZE	HOLES	BOLTS	BOLT QTY
TOP CHORD SIDE SPLICE PLATE	4	5/8"	4" x 2'-5"	1 1/16"	1"ø x 2 1/4" A325 T3	32
TOP CHORD FACE SPLICE PLATE	4	5/8"	5" x 3'-0"	1 1/16"	1"ø x 2 1/4" A325 T3	40
BOTTOM CHORD SIDE SPLICE PLATE	4	5/8"	4" x 2'-5"	1 1/16"	1"ø x 2 1/4" A325 T3	32
BOTTOM CHORD FACE SPLICE PLATE	4	5/8"	5" x 3'-0"	1 1/16"	1"ø x 2 1/4" A325 T3	40
DIAGONAL SPLICE PLATE	4	3/8"	4" x 1'-11"	13/16"	3/4"ø x 4 3/4" A325 T3	16
BRACE DIAGONAL SPLICE PLATE	2	3/8"	3 1/2" x 1'-11"	13/16"	3/4"ø x 6" A325 T3	8
SPLICE BAR	4	1/2"	1" x 8'-2"	–	–	–
DIAGONAL STIFFENER PLATE	4	3/8"	2 1/2" x 0'-11 1/2"	–	–	–
BRACE DIAGONAL STIFFENER PLATE	2	3/8"	3 1/2" x 0'-11 1/2"	–	–	–
STRINGER SPLICE PLATE	4	3/8"	4" x 0'-9"	13/16"	3/4"ø x 1 3/4" A325 T3	4
STRINGER SPLICE PLATE	4	3/8"	4" x 0'-6 1/2"	13/16"	3/4"ø x 1 3/4" A325 T3	2

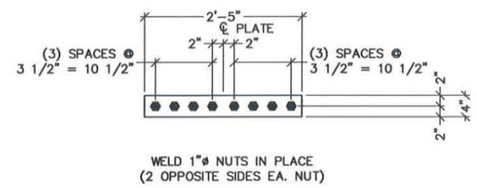


TYPICAL SPLICE STIFFENER

NOTE: STIFFENER PLATES ARE FLUSH ON THE INSIDE OF THE SPLICED DIAGONALS AND SPLICED BRACE DIAGONALS

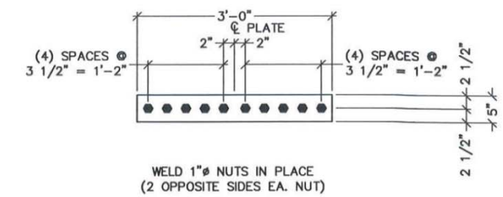


SPLICE DETAILS



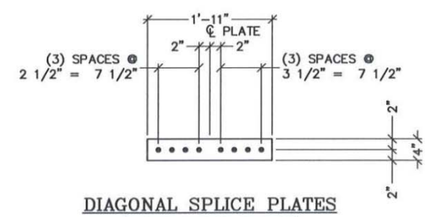
TOP & BOTTOM CHORD SIDE SPLICE PLATES

(LOCATE INSIDE OF TUBE)



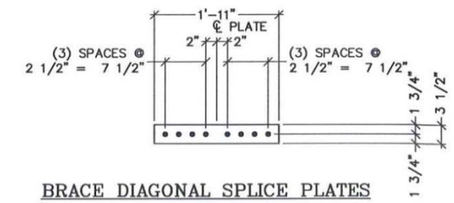
TOP & BOTTOM CHORD FACE SPLICE PLATES

(LOCATE INSIDE OF TUBE)



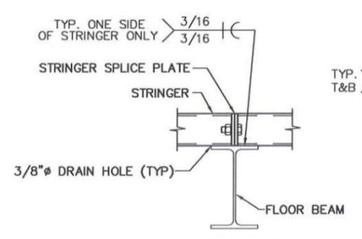
DIAGONAL SPLICE PLATES

(LOCATE OUTSIDE OF TUBE)

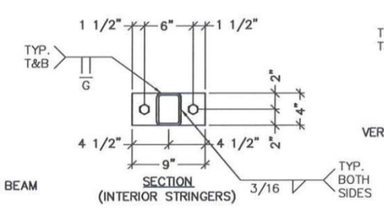


BRACE DIAGONAL SPLICE PLATES

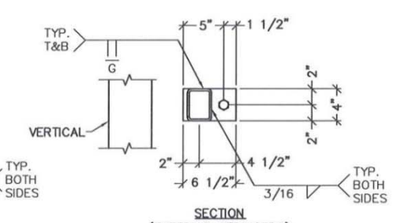
(LOCATE OUTSIDE OF TUBE)



SIDE ELEVATION



SECTION
(INTERIOR STRINGERS)



SECTION
(EXTERIOR STRINGERS)

STRINGER SPLICE DETAIL

(MATERIAL PER SPLICE)

REV	STATUS	BY	DATE
A	ISSUE FOR APPROVAL	XYH	12/06/2013

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(970) 356-9600 • Fax:(970) 356-9621 • www.bigrbridge.com

150'-0" x 8'-0"

SARATOGA PEDESTRIAN BRIDGE

SARATOGA, WY

TOWN OF SARATOGA

Professional Engineer (Civil) SEAN L. JOHNSON 8777 WYOMING Date 12/6/13

BR09-04692

DESIGN BY ENL

DRAWN BY XYH

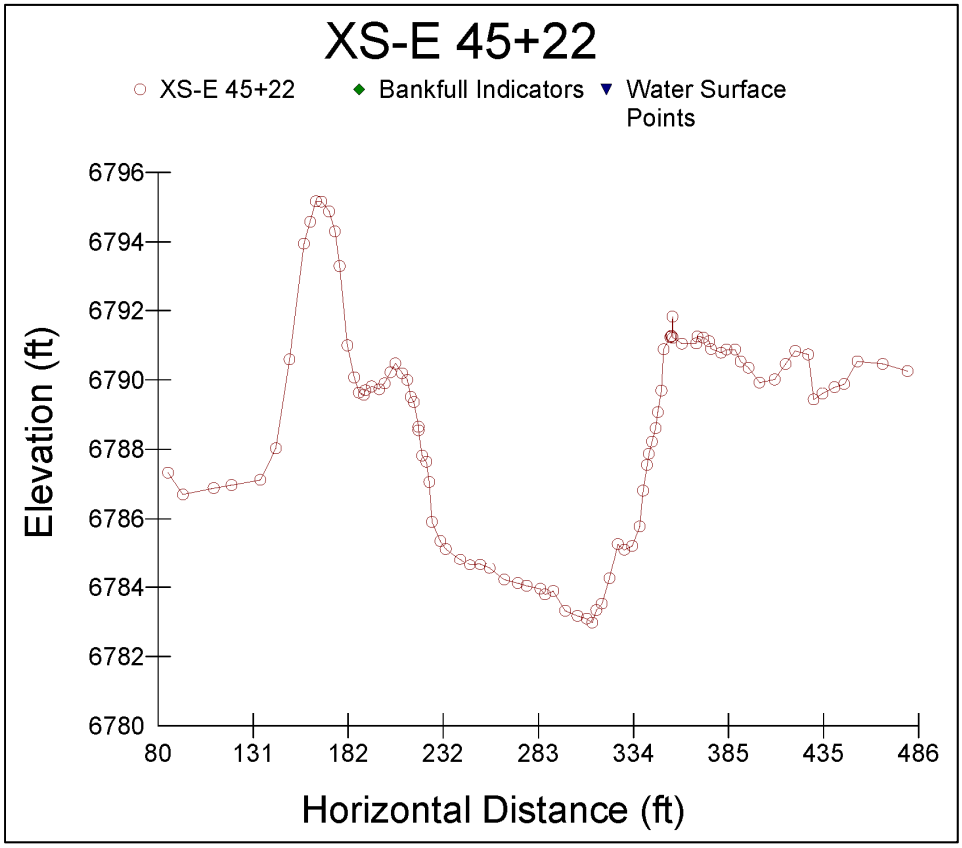
CHECKED BY ENL

SHEET NO. S105 OF S105

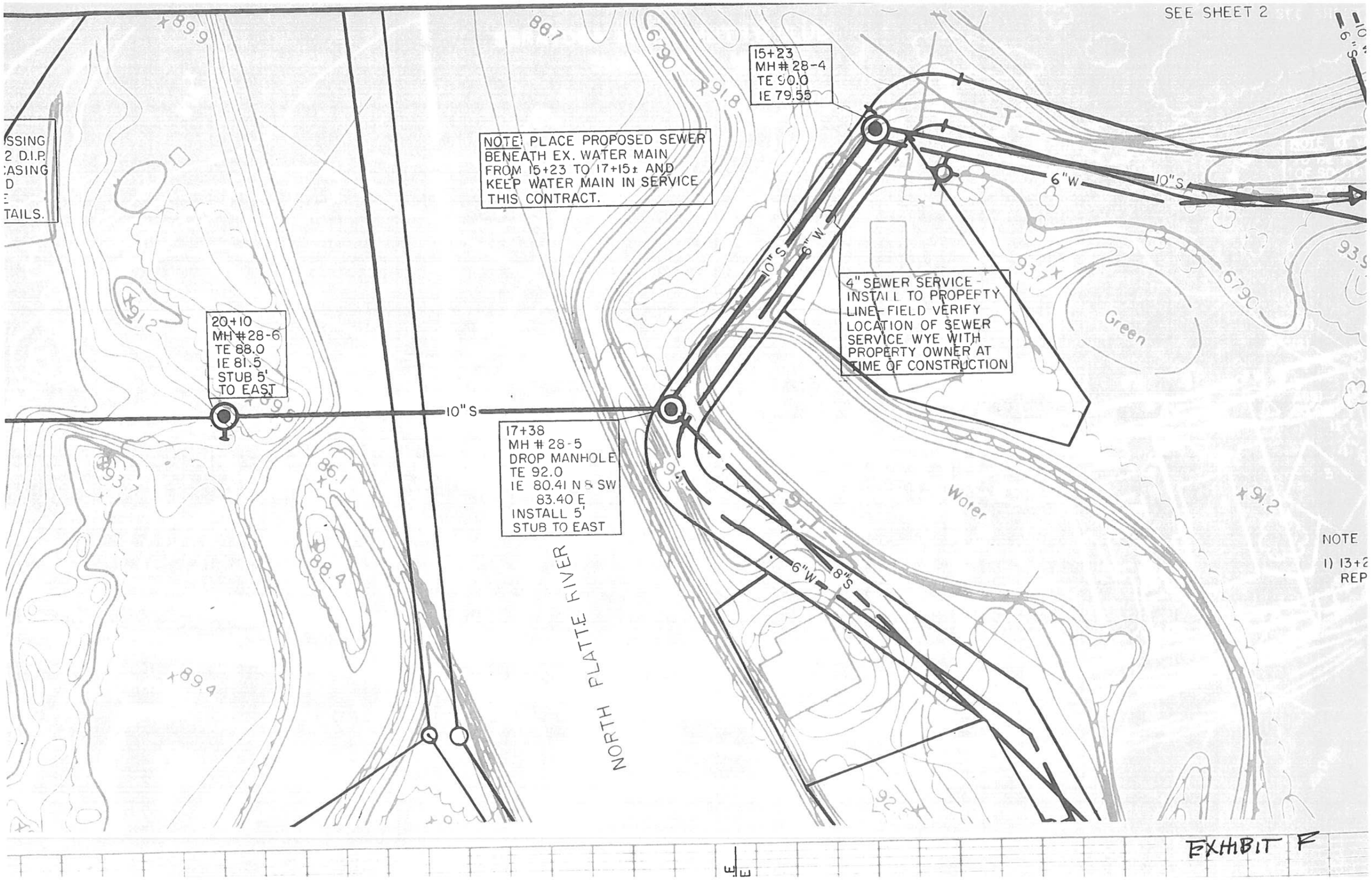
K:\2009\BR09-04692\BR09-04692-P.dwg

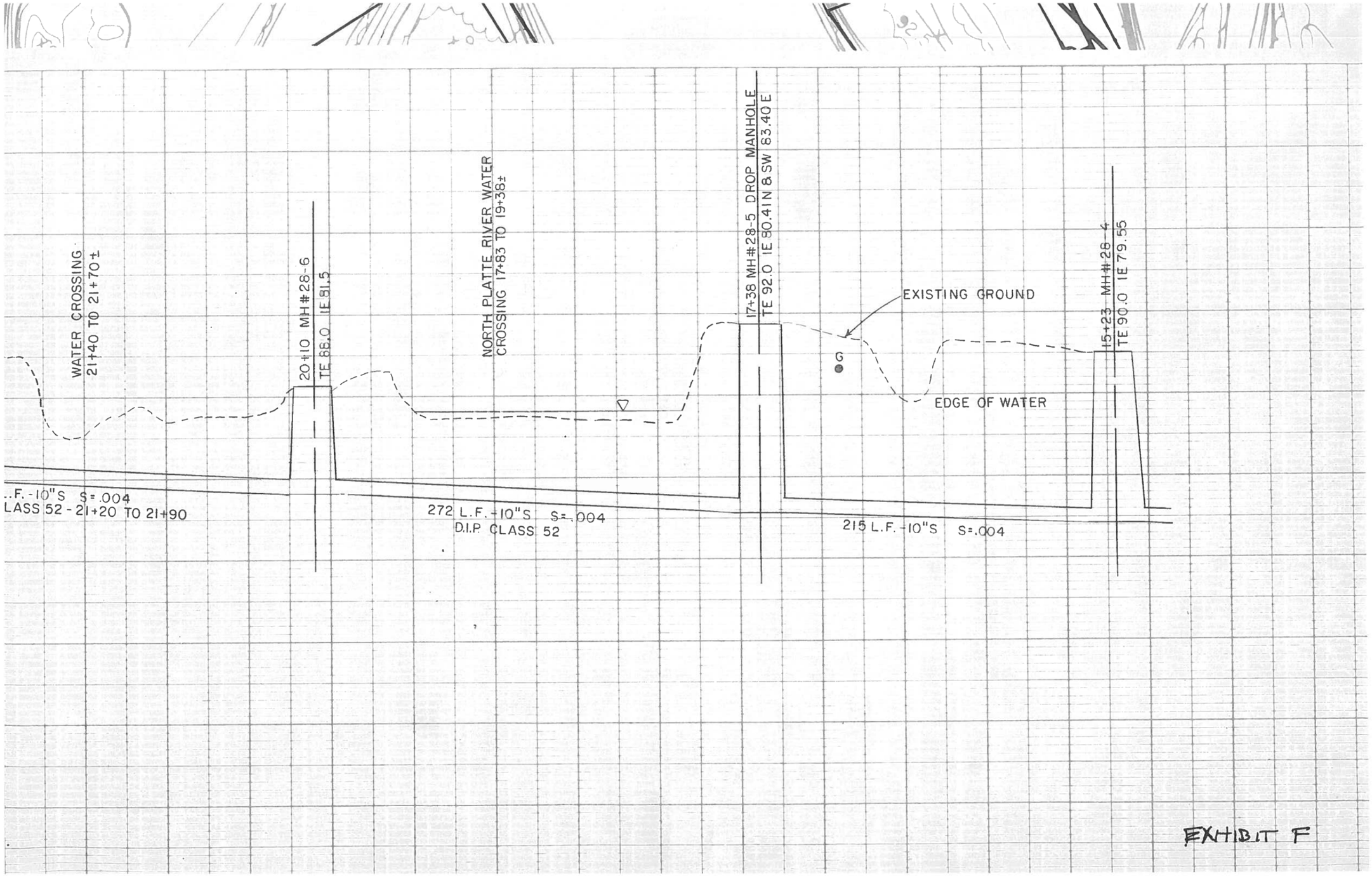
APPENDIX I: CONSTRAINTS (E - PEDESTRIAN BRIDGE LOCATION)

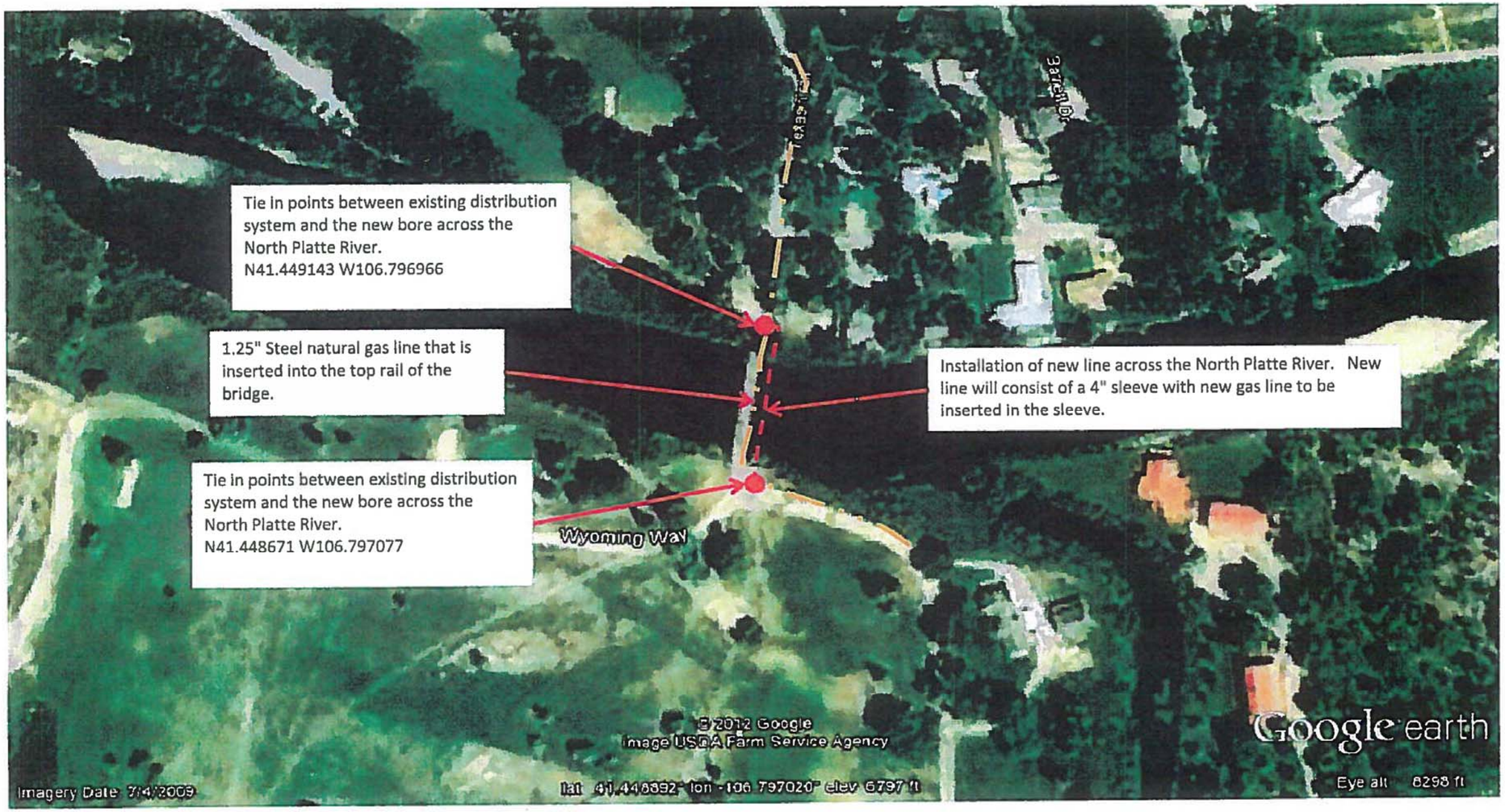
Approximate Location:	East Abutment	Lat. 41° 27.075'N Long. 106° 48.148'W
	West Abutment	Lat. 41° 27.052' N Long. 106° 48.161' W



APPENDIX I: CONSTRAINTS (EXHIBIT F)


SEE SHEET 2
15+23
MH # 28-4
TE 90.0
IE 79.55
NOTE: PLACE PROPOSED SEWER BENEATH EX. WATER MAIN FROM 15+23 TO 17+15± AND KEEP WATER MAIN IN SERVICE THIS CONTRACT.
6"W
10"S
4" SEWER SERVICE - INSTALL TO PROPERTY LINE - FIELD VERIFY LOCATION OF SEWER SERVICE WYE WITH PROPERTY OWNER AT TIME OF CONSTRUCTION
20+10
MH # 28-6
TE 88.0
IE 81.5
STUB 5' TO EAST
10"S
17+38
MH # 28-5
DROP MANHOLE
TE 92.0
IE 80.41 N & SW
83.40 E
INSTALL 5' STUB TO EAST
NORTH PLATTE RIVER
Green
Water
8"S
NOTE
EXHIBIT F

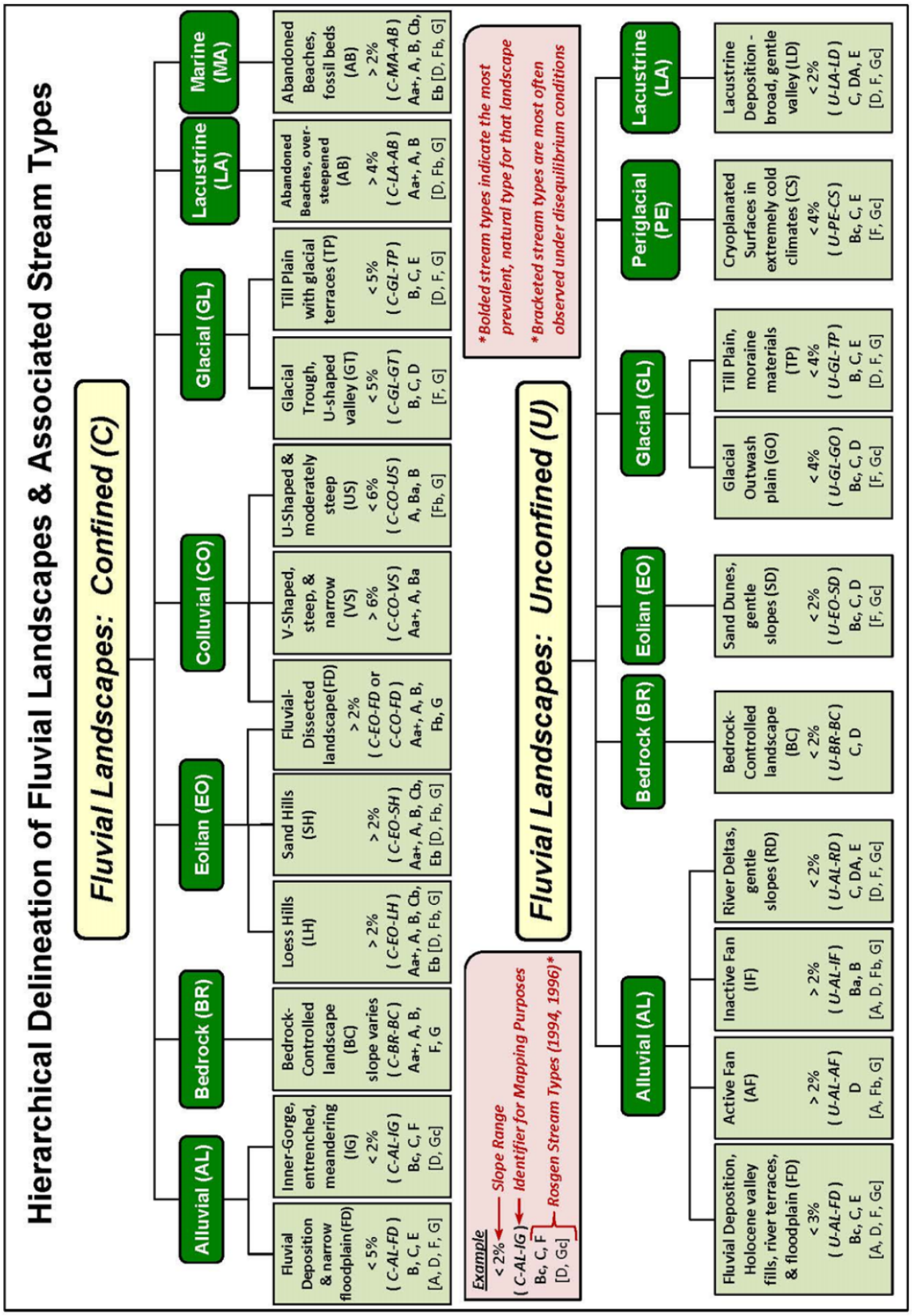

WATER CROSSING
21+40 TO 21+70±
20+10 MH #28-6
TE 88.0 IE 81.5
NORTH PLATTE RIVER WATER
CROSSING 17+83 TO 19+36±
17+38 MH #28-5 DROP MANHOLE
TE 92.0 IE 80.41 N & SW 83.40 E
EXISTING GROUND
G
EDGE OF WATER
15+23 MH #28-4
TE 90.0 IE 79.55
..F.-10"S S=.004
LASS 52 - 21+20 TO 21+90
272 L.F.-10"S S=.004
D.I.P. CLASS 52
215 L.F.-10"S S=.004
EXHIBIT F



Currently, there is a 1.25" steel natural gas distribution line that crosses the North Platte River via the railing of the bridge. On either side of the bridge, there will be excavation to expose the existing mai At those two locations there will be connection points for the new main that will be bored across the river. The new crossing will be a 4" PE sleeve with a 2" PE natural gas line inserted through the 4" sleeve. At the location of the of the tie in points there will be test stations installed along with anodes to insure the cathodic protection of the steel lines in the immediate area. Line markers will also be installed at the location of the tie in points as close to the point of connection without interfereing with the roadway.

EXHIBIT H

APPENDIX II: FLUVIAL LANDSCAPES



Valley Type in Rosgen (1996)	New Identifier for Mapping	Delineation of Fluvial Landscapes	Slope Range	Associated Stream Types*
I	*C-CO-VS*	***Confined Colluvial:*** V-Shaped, Steep, & Narrow	*> 6%*	**Aa+, A, Ba**
II	*C-CO-US*	***Confined Colluvial:*** U-Shaped & Moderately Steep	*< 6%*	**A, Ba, B** [Fb, G]
III	*U-AL-AF*	***Unconfined Alluvial:*** Active Fan	*> 2%*	**D** [A, Fb, G]
	U-AL-IF	***Unconfined Alluvial:*** Inactive Fan	*> 2%*	**Ba, B** [A, D, Fb, G]
IV	*C-AL-IG*	***Confined Alluvial:*** Inner-Gorge – Entrenched & Meandering	*< 2%*	**Bc, C, F** [D, Gc]
V	*C-GL-GT*	***Confined Glacial:*** Glacial Trough, U-Shaped Valley	*< 5%*	**B, C, D** [F, G]
VI	*C-BR-BC*	***Confined Bedrock:*** Bedrock-Controlled Landscape	*varies*	**Aa+, A, B, F, G**
	U-BR-BC	***Unconfined Bedrock:*** Bedrock-Controlled Landscape	*< 2%*	**C, D**
VII	*C-EO-FD or C-CO-FD*	***Confined Eolian or Colluvial:*** Fluvial-Dissected Landscape	*> 2%*	**Aa+, A, B, Fb, G**
VIII	*C-AL-FD*	***Confined Alluvial:*** Fluvial Deposition & Narrow Floodplain	*< 5%*	**B, C, E** [A, D, F, G]
	U-AL-FD	***Unconfined Alluvial:*** Fluvial Deposition, Holocene Valley Fills, River Terraces, & Floodplain	*< 3%*	**Bc, C, E** [A, D, F, Gc]
IX	*U-GL-GO*	***Unconfined Glacial:*** Glacial Outwash Plain	*< 4%*	**Bc, C, D** [F, Gc]
X	*U-LA-LD*	***Unconfined Lacustrine:*** Lacustrine Deposition - Broad, Gentle Valley	*< 2%*	**C, DA, E** [D, F, Gc]
XI	*U-AL-RD*	***Unconfined Alluvial:*** River Deltas, Gentle Slopes	*< 2%*	**C, DA, E** [D, F, Gc]
	C-EO-LH	***Confined Eolian:*** Loess Hills	*> 2%*	**Aa+, A, B, Cb, Eb** [D, Fb, G]
	C-EO-SH	***Confined Eolian:*** Sand Hills	*> 2%*	**Aa+, A, B, Cb, Eb** [D, Fb, G]
	C-GL-TP	***Confined Glacial:*** Till Plain with Glacial Terraces	*< 5%*	**B, C, E** [D, F, G]
	C-LA-AB	***Confined Lacustrine:*** Abandoned Beaches, Over-Steepened	*> 4%*	**Aa+, A, B** [D, Fb, G]
	C-MA-AB	***Confined Marine:*** Abandoned Beaches, Fossil Beds	*> 2%*	**Aa+, A, B, Cb, Eb** [D, Fb, G]
	U-EO-SD	***Unconfined Eolian:*** Sand Dunes, Gentle Slopes	*< 2%*	**Bc, C, D** [F, Gc]
	U-GL-TP	***Unconfined Glacial:*** Till Plain, Moraine Materials	*< 4%*	**B, C, E** [D, F, G]
	U-PE-CS	***Unconfined Periglacial:*** Cryoplanated Surfaces in Extremely Cold Climates	*< 4%*	**Bc, C, E** [F, Gc]

**Bolded stream types indicate the most prevalent, natural type for that landscape; Bracketed stream types are most often observed under disequilibrium conditions*

The North Platte River through Saratoga –

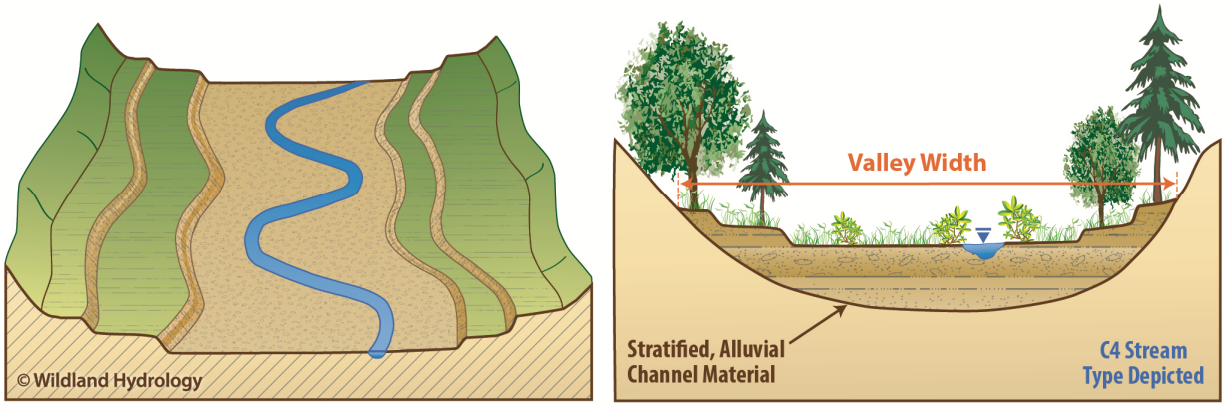
Unconfined Alluvial: Fluvial Deposition with Terraces and Floodplain (U-AL-FD)

This unconfined alluvial valley is identified by the presence of multiple river terraces positioned parallel to the present river along broad, wide valleys (valley width ratio values of 7.0 or greater) with gentle, down-valley elevational relief (valley slopes less than 3.0%). Alluvial terraces and floodplains are the predominant depositional landforms, which can produce a high sediment supply related to streambank erosional processes depending on the riparian vegetation. Pleistocene terraces can also occur in these valleys but their surfaces are much higher above the present river than the Holocene terraces. Terrace types can be distinguished to identify the sometimes complex geomorphic histories involving past erosional and depositional processes, such as *fill terraces* and *cut terraces* (Leopold *et al*., 1964).

Riparian communities composed of wetlands and a variety of species are typical. The riparian community is critical for the stability and physical, biological, and chemical functions of the alluvial stream types associated with this valley type (Brooks and Brierley, 2002). Due to the presence of shallow water tables and the water holding capacity of alluvium, diverse, productive plan communities exist, including dense overstory, midstory, and understory stands. These communities range from selected conifers and deciduous trees that can withstand infrequent to frequent inundation on saturated soils, such as bald cypress and mixed hardwoods, to a variety of understory woody plants. Large woody debris can be recruited from the floodplain and terraces; certain shallow-rooted riparian species are susceptible to streambank erosion and contribute to the large woody debris in the channel.

The flow regimes are mostly perennial with stormflow, rain-on-snow, glacial-fed, spring-fed, and snowmelt-dominated hydrographs. The dimension, pattern, and profile of the river channels are closely linked to the bankfull discharge. Channel adjustment is related to changes in the flow and sediment regimes as well as the riparian vegetation. This alluvial valley is most commonly associated with B_c, C, and E stream types that are slightly entrenched, meandering channels that develop riffle–pool bedforms; however, the A, D, F, and G_c stream types also occur most often under disequilibrium conditions.

***Unconfined Alluvial:* Fluvial Deposition, Terraces, & Floodplain (*U-AL-FD*)**



Landscape Slope: < 3% Stream Types: **B_c**, **C**, **E**, [A, D, F, G_c]

Unconfined, terraced alluvial valley, C4 stream type, Llano River, TX.

Unconfined, terraced alluvial valley, C4 stream type, Tarryal Creek, CO.

APPENDIX III: STREAM CLASSIFICATION

The nature and range of the dependent form variables representing stream morphology were delineated to help describe the variety of stream types that occur in nature. These types were determined using measured data representing hundreds of rivers between 1969 and 1994 (Rosgen, 1994, 1996). Resultant stream types are a reflection of mutually adjusting variables that describe their unique sedimentological, hydraulic, morphological, and biological characteristics and processes. The system is based on parameters of form and pattern but has the advantage of implying channel behavior.

The broad-level stream classification identifies eight major morphological stream types: A, B, C, D, DA, E, F, and G (Rosgen, 1994, 1996). Because stream morphology is the product of the integrative processes combining the boundary conditions and driving variables, the morphological variables that can be easily and consistently measured are used as delineative criteria. The selected criteria represent variables that govern channel morphology based on theory and research, and are based primarily on the bankfull stage morphology of the river. However, rather than using the absolute measures of dimension, pattern, and profile, the classification is based on dimensionless parameters required for scaling purposes. The delineative criteria are associated with stream pattern (sinuosity and single-thread versus multiple channels), shape (width/depth ratio), longitudinal profile (channel slope) and vertical containment (entrenchment ratio). These delineative criteria interact with one another to produce a stream's dominant features and reflect unique fluvial processes.

The broad-level stream types are further delineated by dominant channel materials along a continuum of gradient ranges. The initial stream type is subdivided by its dominant channel bed-material size: bedrock (1), boulder (2), cobble (3), gravel (4), sand (5), and silt/clay (6). In total, 41 primary stream types exist. Subcategories of slope are also utilized along a slope continuum where the combined morphological variables are consistent for a stream type. However, for a particular stream reach that is steeper or flatter than the normal range of that type, a small letter sub-category is used to best reflect actual variables (Rosgen, 1994, p. 181): a+ (steeper than 0.10), a (0.04–0.10; slopes typical of A stream types), b (0.02–0.04; slopes typical of B stream types), c (0.001–0.02; slopes typical of C stream types), and c- (less than 0.001). For example, the Aa+ stream type is similar to the A stream type in all the delineative criteria except the Aa+ stream type has a steeper slope greater than 0.10. The delineative criteria for stream classification are discussed further.

Entrenchment is the vertical containment of a river and the degree to which it is incised in the valley floor. This delineative criterion is important to interpret floodplain connectivity and whether the flat adjacent to the channel is a frequent floodplain, a terrace (abandoned floodplain) or is outside of a flood-prone area (Rosgen, 1994, 1996). *Entrenchment ratio* was thus developed as the quantitative index defined as the flood-prone area width to bankfull width. The flood-prone area width is obtained at an elevation at two times the maximum bankfull depth at a riffle cross-section location and perpendicular to the fall line of the valley. If the entrenchment ratio is less than 1.4 (± 0.2 to allow for the continuum of channel form), the stream is classified as entrenched or vertically contained and is characteristic of no active floodplain and in some instances river terraces (A, G, and F stream types). If the entrenchment ratio is between 1.4 and 2.2, (+ or – 0.2), the stream is moderately entrenched and is characteristic of an active flood-prone area but not an adjacent, flat floodplain (B stream types). If the ratio is

greater than 2.2, the stream is not entrenched and has a well-developed floodplain (C, E, and DA stream types).

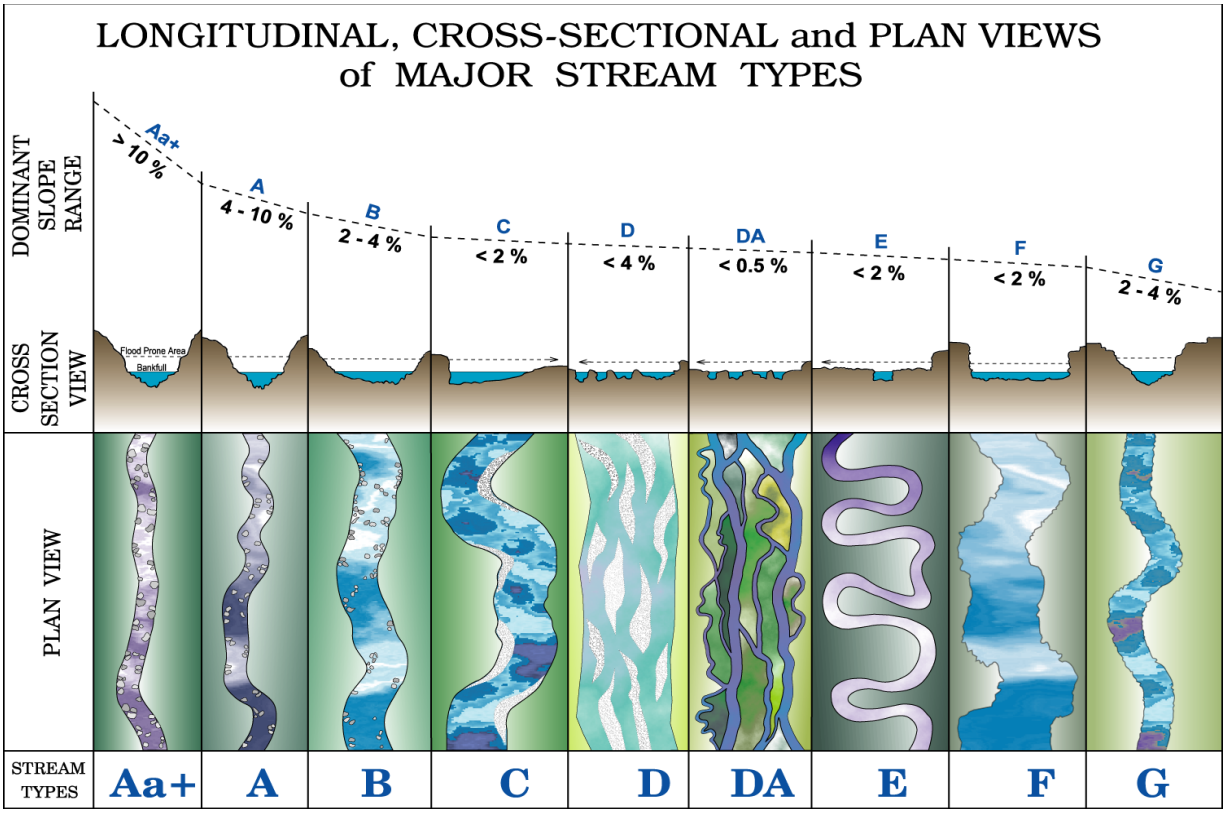
Width/depth ratio describes the dimension and shape factor determined from a riffle cross-section based on bankfull surface width divided by bankfull mean depth (Rosgen, 1994, 1996). Width/depth ratio varies primarily with the dimension of the channel cross-section for a given slope, the boundary roughness as a function of streamflow and sediment regime, streambank erodibility factors including the nature of streambank materials, the degree of entrenchment (vertical containment), and the distribution of energy (boundary stress) in the stream channel. Moderate and high width/depth ratios greater than 12 are associated with wide, shallow streams. Conversely, low width/depth ratios less than 12 are associated with narrow, deep channels.

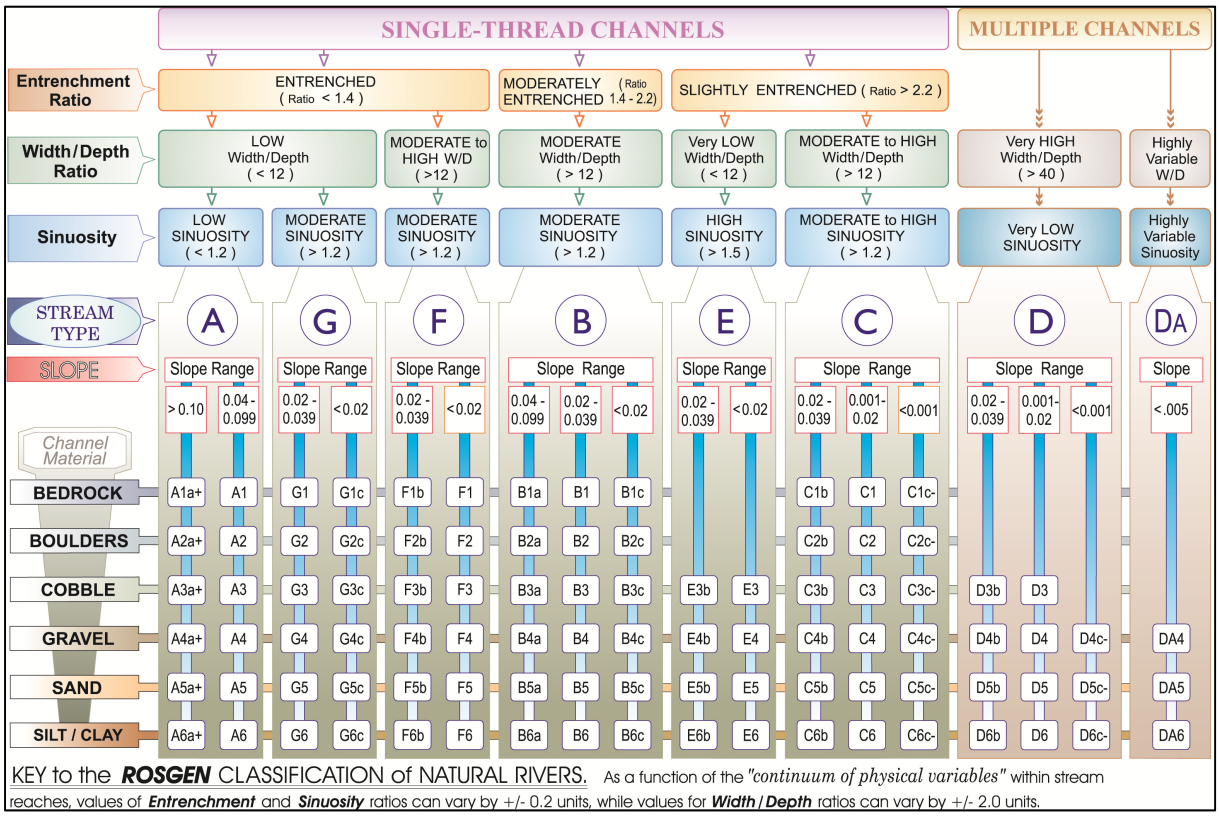
Channel patterns are naturally developed that affect the resistance to flow and provide for the dissipation of the kinetic energy of moving water and the transportation of sediment (Leopold *et al*., 1964; Rosgen, 1996). Single-thread rivers are classed as relatively straight (A stream types), low sinuosity (B and G stream types), meandering (C and F stream types), and tortuously meandering (E stream types). Complex stream patterns are found in the multiple channel, braided D stream types and the anastomosed DA stream types.

Sinuosity (defined as the ratio of channel length to valley length or the ratio of valley slope to channel slope) was also selected as one of the delineative criteria for stream classification because of its relation to channel dimensions, sediment load, streamflow and the streambank and bed materials (Rosgen, 1994, 1996). Numerous researchers have demonstrated the interrelationship between sinuosity and meander geometry following minimum expenditure of energy concepts. The river pattern exhibits natural adjustments in sinuosity that result in maintaining a slope adjusted to that of its valley to balance sediment loads and the energy available from streamflow to perform work (Rosgen, 1996).

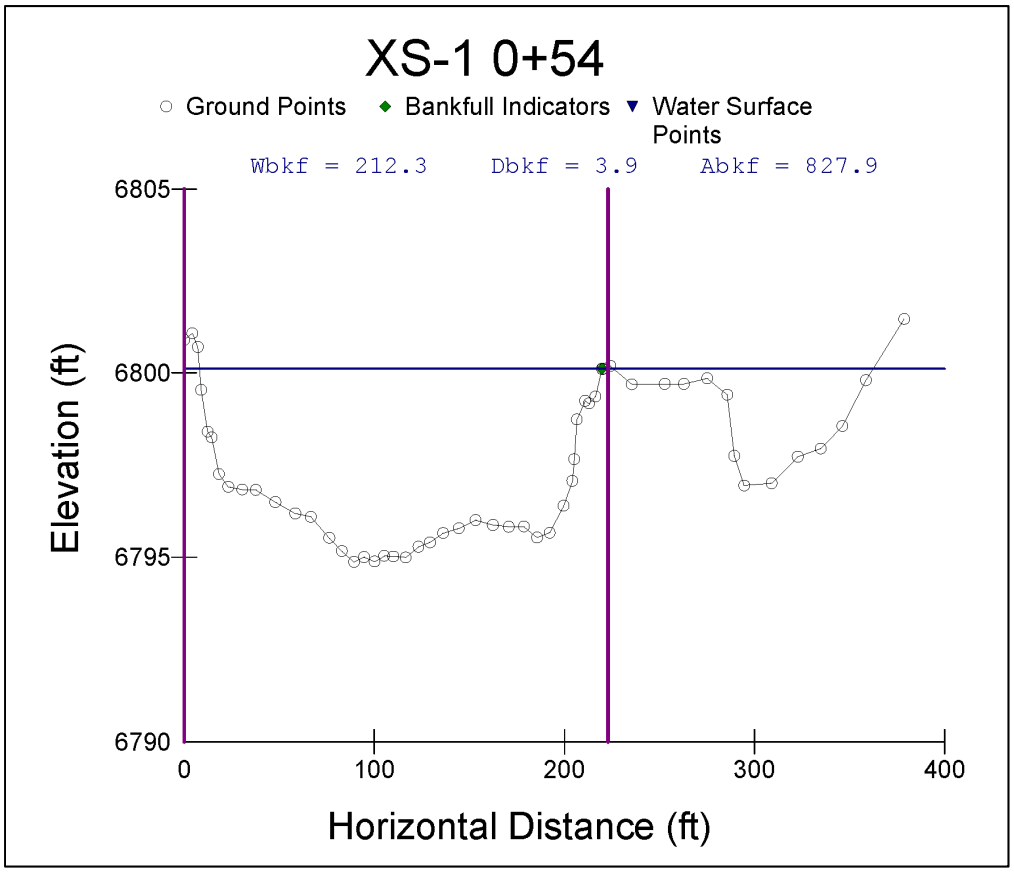
Channel slope is used in stream classification to reflect profile morphology and describe bed morphology. Generally, channel slope decreases in the downstream direction with commensurate increases in streamflow and a corresponding general decrease in sediment size. Channel slope is inversely proportional to sinuosity and also pool-to-pool spacing, indicating that as gradient increases, sinuosity decreases and the spacing between pools decreases. The Aa+ stream type is very steep with frequently-spaced, vertical drop, scour-pool, step bed features that tend to be high debris transport streams and/or waterfalls. The A stream type is steep with cascading, step–pool bed features. The B stream type is riffle-dominated with rapids and infrequently spaced scour-pools at bends or areas of constriction. The C, DA, E, and F stream types are gentle-gradient, riffle–pool streams. The G stream type is a "gulley" and typically reflects step–pools channels. Last, the D stream type is braided, typical of convergence–divergence processes that lead to localized, frequently-spaced scour/depositional bed forms.

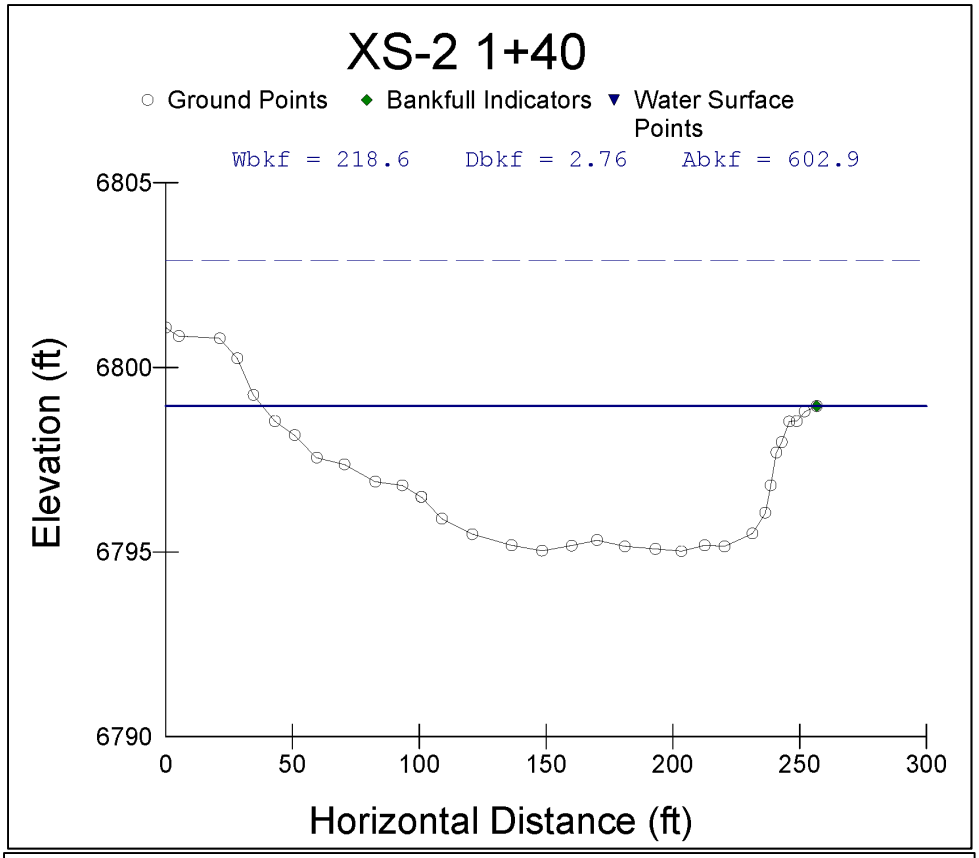
Stream Type	General Description	Entrench-ment Ratio	W/d Ratio	Sinuosity	Slope	Landform / Soils / Features
Aa+	Very steep, deeply entrenched, debris transport, torrent streams.	<1.4	<12	1.0 to 1.1	>0.10	Very high relief. Erosional, bedrock or depositional features; debris flow potential. Deeply entrenched streams. Vertical steps with deep scour pools; waterfalls.
A	Steep, entrenched, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock- or boulder-dominated channel.	<1.4	<12	1.0 to 1.2	0.04 to 0.10	High relief. Erosional or depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step/pool bed morphology.
B	Moderately entrenched, moderate gradient, riffle-dominated channel, with infrequently spaced pools. Very stable plan and profile. Stable banks.	1.4 to 2.2	>12	>1.2	0.02 to 0.039	Moderate relief, colluvial deposition and/or structural. Moderate entrenchment and width/depth ratio. Narrow, gently sloping valleys. Rapids predominate with scour pools.
C	Low gradient, meandering, point bar, riffle/pool, alluvial channels with broad, well-defined floodplains.	>2.2	>12	>1.2	<0.02	Broad valleys with terraces in association with floodplains, alluvial soils. Slightly entrenched with well-defined meandering channels. Riffle–pool bed morphology.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.	n/a	>40	n/a	<0.04	Broad valleys with alluvium, steeper fans. Glacial debris and depositional features. Active lateral adjustment with abundance of sediment supply. Convergence–divergence of bed features, aggradational processes, high bedload and bank erosion.
DA	Anastomosing (multiple channels) narrow and deep with extensive, well-vegetated floodplains and associated wetlands. Very gentle relief with highly variable sinuosities and width/depth ratios. Very stable streambanks.	>2.2	Highly Variable	Highly Variable	<0.005	Broad, low-gradient valleys with fine alluvium or lacustrine soils. Anastomosed (multiple channel) geologic control creating fine deposition with well-vegetated bars that are laterally stable with broad wetland floodplains. Very low bedload, high washload sediment.
E	Low gradient, meandering riffle/pool stream with low width/depth ratio and little deposition. Very efficient and stable. High meander width ratio.	>2.2	<12	>1.5	<0.02	Broad valley and meadows. Alluvial materials with floodplains. Highly sinuous with stable, well-vegetated banks. Riffle–pool morphology with very low width/depth ratios.
F	Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio.	<1.4	>12	>1.2	<0.02	Entrenched in highly weathered material. Gentle gradients with a high width/depth ratio. Meandering, laterally unstable with high bank erosion rates. Riffle–pool morphology.
G	Entrenched “gully” step/pool and low width/depth ratio on moderate gradients.	<1.4	<12	>1.2	<0.039	Gullies, step–pool morphology with moderate slopes & low width/depth ratio. Narrow valleys, or deeply incised in alluvial or colluvial materials; i.e., fans or deltas. Unstable, with grade control problems and high bank erosion rates.

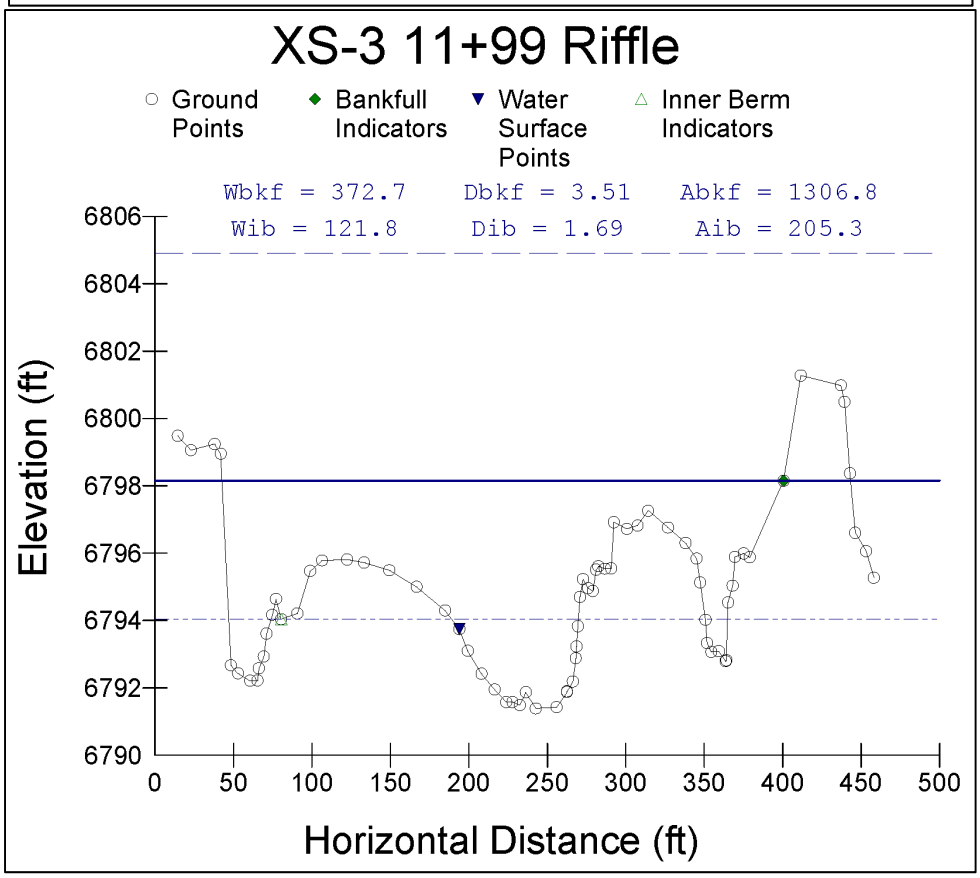

LONGITUDINAL, CROSS-SECTIONAL and PLAN VIEWS
of MAJOR STREAM TYPES
DOMINANT SLOPE RANGE
Aa+
> 10 %
A
4 - 10 %
B
2 - 4 %
C
< 2 %
D
< 4 %
DA
< 0.5 %
E
< 2 %
F
< 2 %
G
2 - 4 %
CROSS SECTION VIEW
Flood Prone Area
Bankfull
PLAN VIEW
STREAM TYPES
Aa+
A
B
C
D
DA
E
F
G

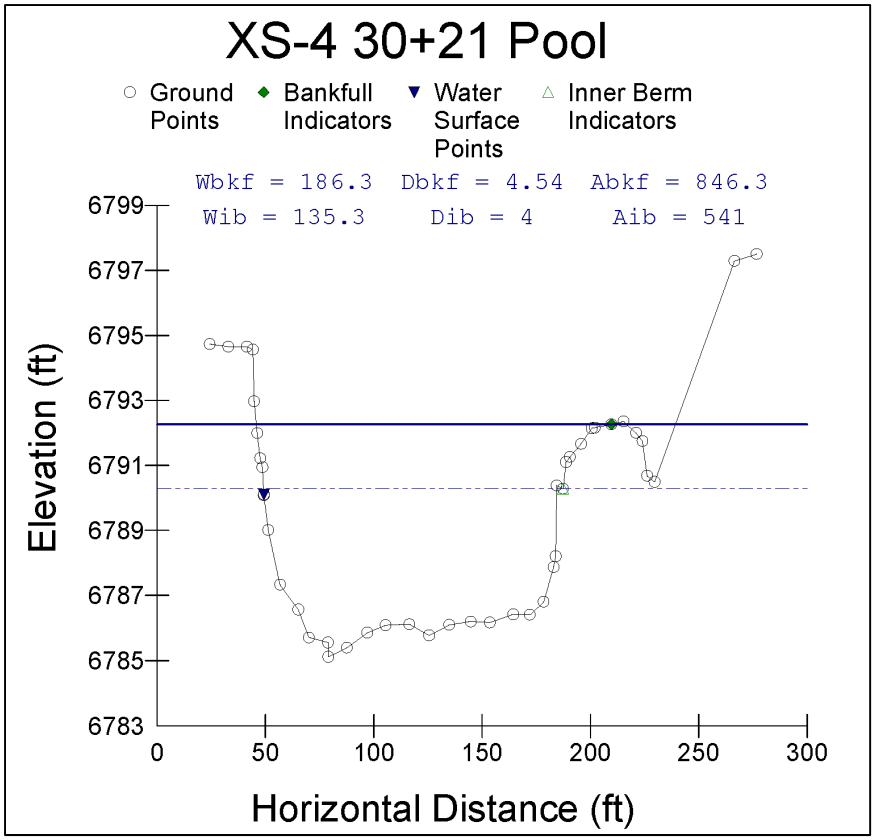

SINGLE-THREAD CHANNELS
MULTIPLE CHANNELS
Entrenchment Ratio
ENTRENCHED (Ratio < 1.4)
MODERATELY ENTRENCHED (Ratio 1.4 - 2.2)
SLIGHTLY ENTRENCHED (Ratio > 2.2)
Width/Depth Ratio
LOW Width/Depth (< 12)
MODERATE to HIGH W/D (>12)
MODERATE Width/Depth (> 12)
Very LOW Width/Depth (< 12)
MODERATE to HIGH Width/Depth (> 12)
Very HIGH Width/Depth (> 40)
Highly Variable W/D
Sinuosity
LOW SINUOSITY (< 1.2)
MODERATE SINUOSITY (> 1.2)
MODERATE SINUOSITY (> 1.2)
MODERATE SINUOSITY (> 1.2)
HIGH SINUOSITY (> 1.5)
MODERATE to HIGH SINUOSITY (> 1.2)
Very LOW SINUOSITY
Highly Variable Sinuosity
STREAM TYPE
A
G
F
B
E
C
D
DA
SLOPE
Slope Range
Slope
> 0.10
0.04 - 0.099
0.02 - 0.039
<0.02
0.001- 0.02
<0.001
< .005
Channel Material
BEDROCK
BOULDERS
COBBLE
GRAVEL
SAND
SILT / CLAY
A1a+ A1 G1 G1c F1b F1 B1a B1 B1c C1b C1 C1c- D3b D3 DA4
A2a+ A2 G2 G2c F2b F2 B2a B2 B2c C2b C2 C2c- D4b D4 D4c- DA5
A3a+ A3 G3 G3c F3b F3 B3a B3 B3c E3b E3 C3b C3 C3c- D5b D5 D5c- DA6
A4a+ A4 G4 G4c F4b F4 B4a B4 B4c E4b E4 C4b C4 C4c- D6b D6 D6c-
A5a+ A5 G5 G5c F5b F5 B5a B5 B5c E5b E5 C5b C5 C5c-
A6a+ A6 G6 G6c F6b F6 B6a B6 B6c E6b E6 C6b C6 C6c-
KEY to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the "continuum of physical variables" within stream reaches, values of Entrenchment and Sinuosity ratios can vary by +/- 0.2 units, while values for Width/Depth ratios can vary by +/- 2.0 units.

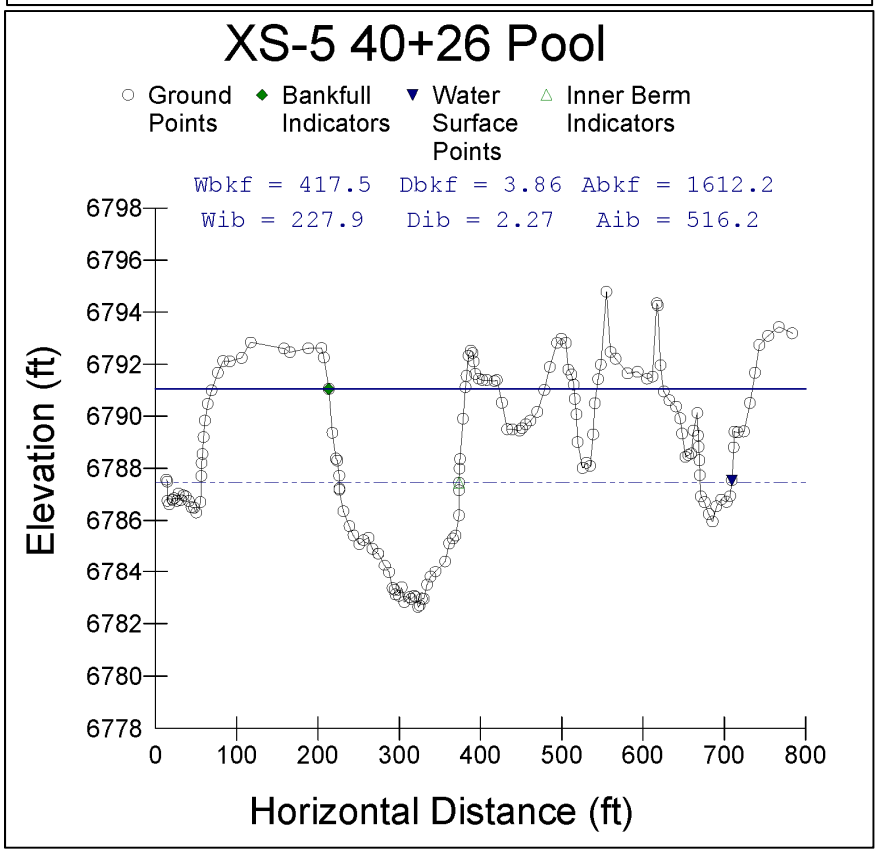
APPENDIX IV: CROSS-SECTION DIMENSIONS

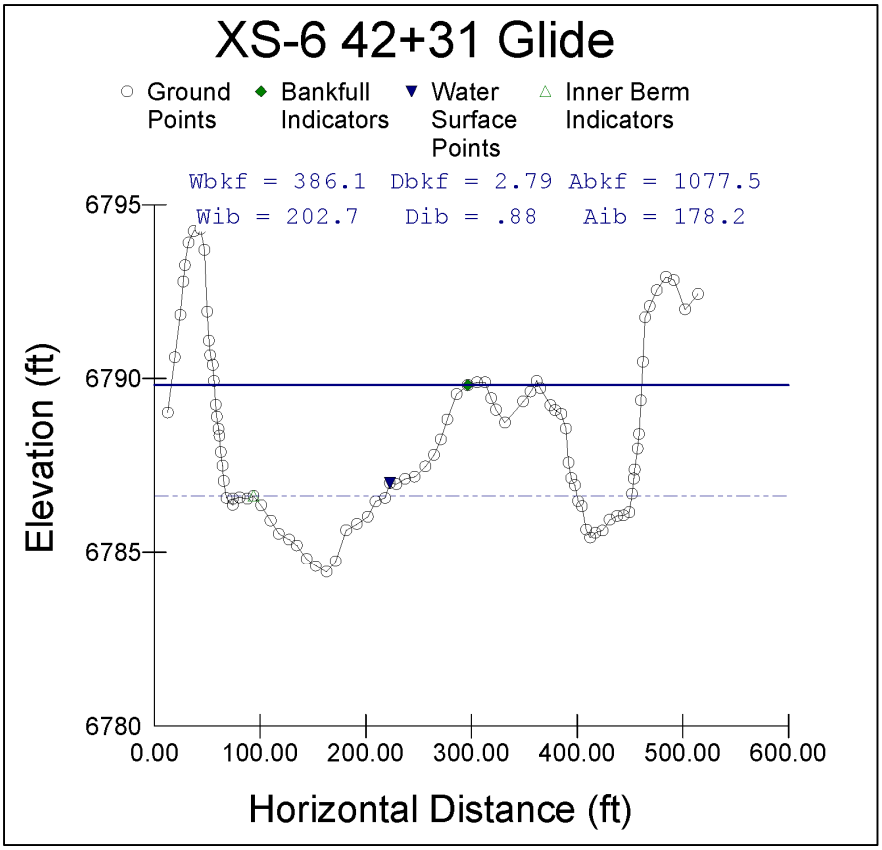


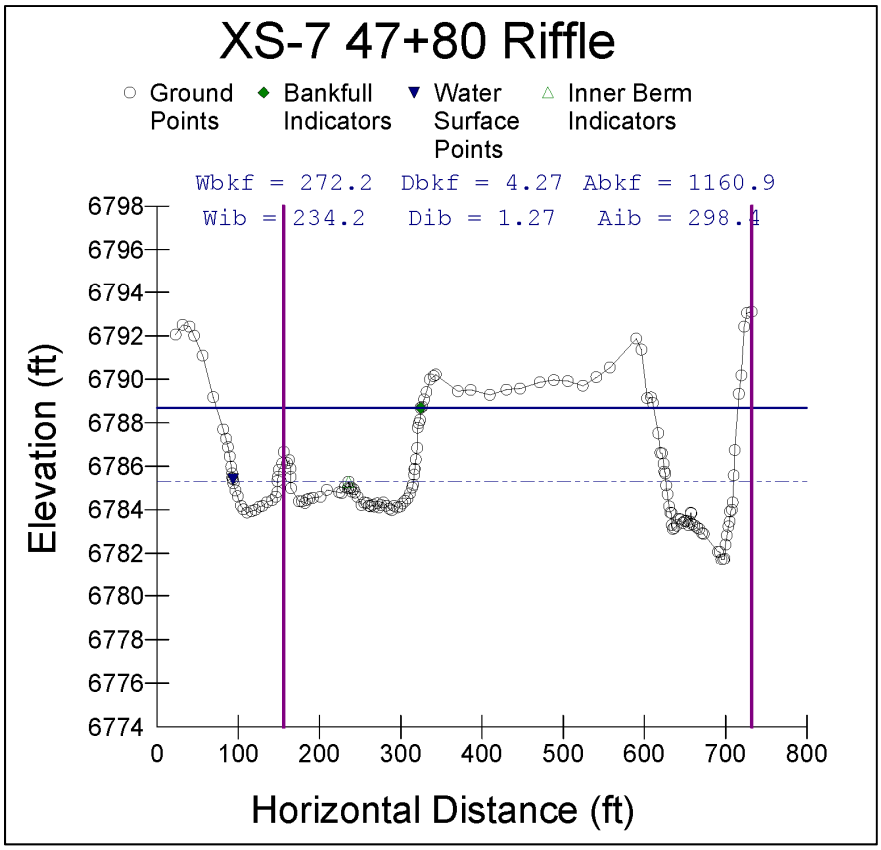

XS-2 1+40
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 218.6
Dbkf = 2.76
Abkf = 602.9
Elevation (ft)
6805
6800
6795
6790
0
50
100
150
200
250
300
Horizontal Distance (ft)

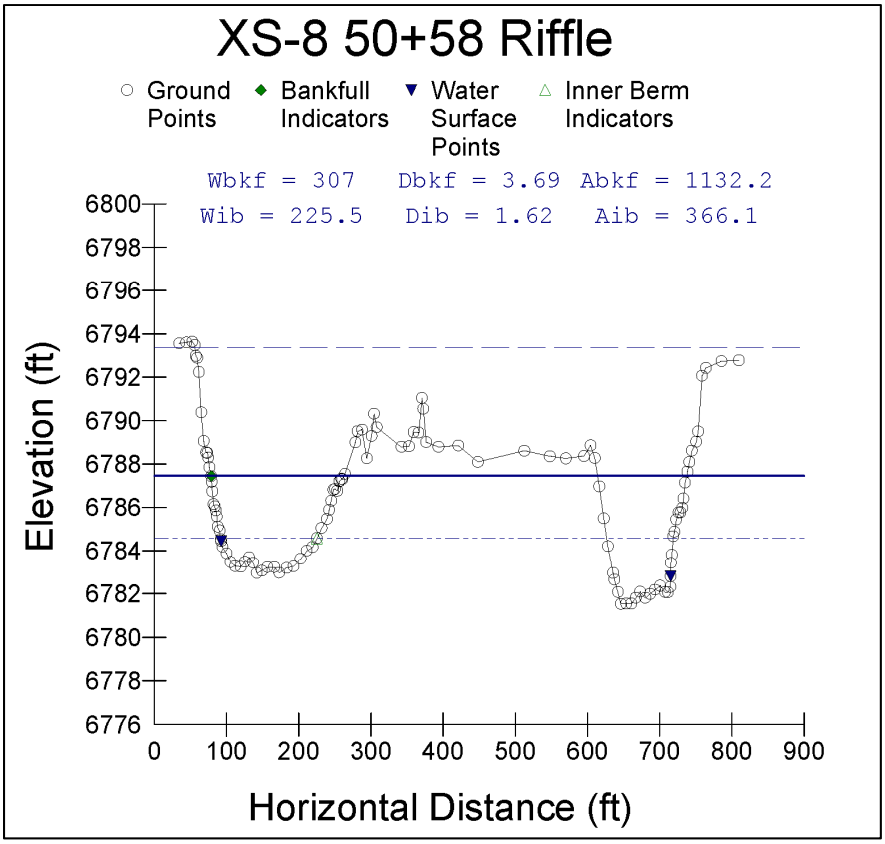

XS-3 11+99 Riffle
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 372.7
Dbkf = 3.51
Abkf = 1306.8
Wib = 121.8
Dib = 1.69
Aib = 205.3
Elevation (ft)
6806
6804
6802
6800
6798
6796
6794
6792
6790
0
50
100
150
200
250
300
350
400
450
500
Horizontal Distance (ft)

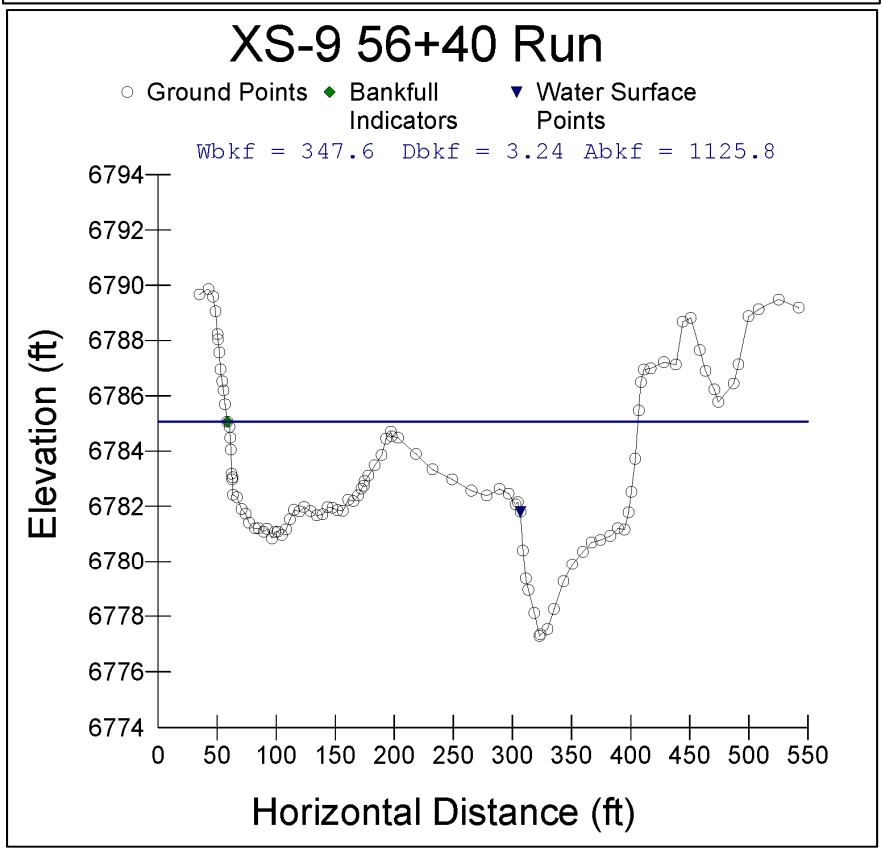

XS-4 30+21 Pool
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 186.3 Dbkf = 4.54 Abkf = 846.3
Wib = 135.3 Dib = 4 Aib = 541
Elevation (ft)
6799
6797
6795
6793
6791
6789
6787
6785
6783
0
50
100
150
200
250
300
Horizontal Distance (ft)

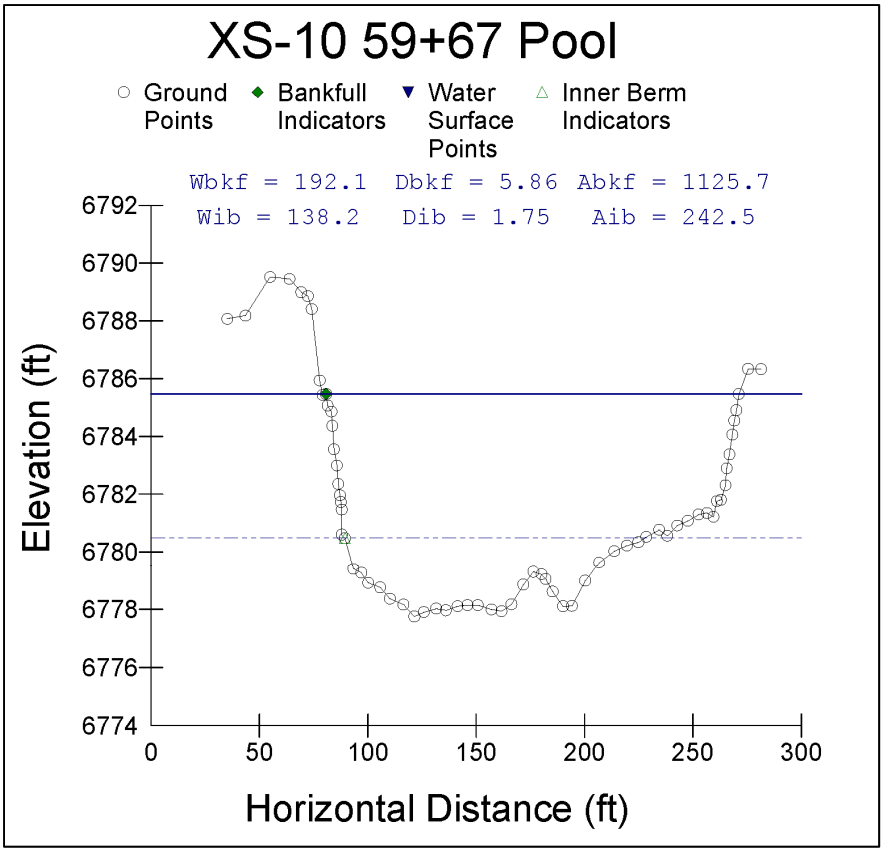

XS-5 40+26 Pool
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 417.5 Dbkf = 3.86 Abkf = 1612.2
Wib = 227.9 Dib = 2.27 Aib = 516.2
Elevation (ft)
6798
6796
6794
6792
6790
6788
6786
6784
6782
6780
6778
0
100
200
300
400
500
600
700
800
Horizontal Distance (ft)

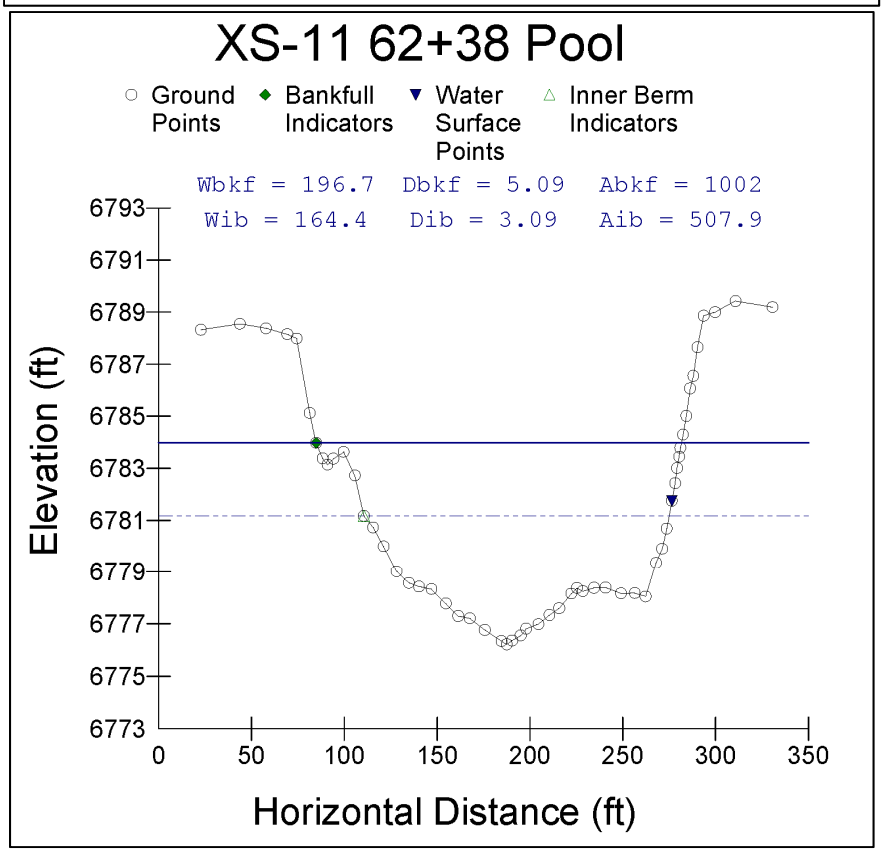

XS-6 42+31 Glide
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 386.1 Dbkf = 2.79 Abkf = 1077.5
Wib = 202.7 Dib = .88 Aib = 178.2
Elevation (ft)
6795
6790
6785
6780
0.00
100.00
200.00
300.00
400.00
500.00
600.00
Horizontal Distance (ft)

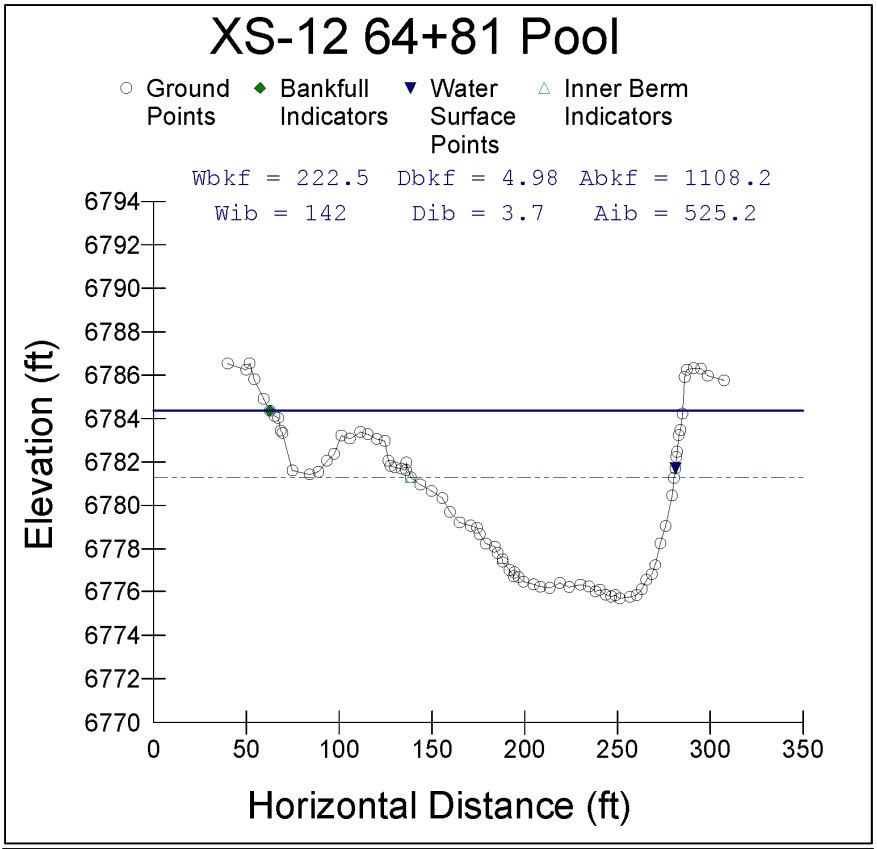

XS-7 47+80 Riffle
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 272.2 Dbkf = 4.27 Abkf = 1160.9
Wib = 234.2 Dib = 1.27 Aib = 298.4
Elevation (ft)
6798
6796
6794
6792
6790
6788
6786
6784
6782
6780
6778
6776
6774
0
100
200
300
400
500
600
700
800
Horizontal Distance (ft)

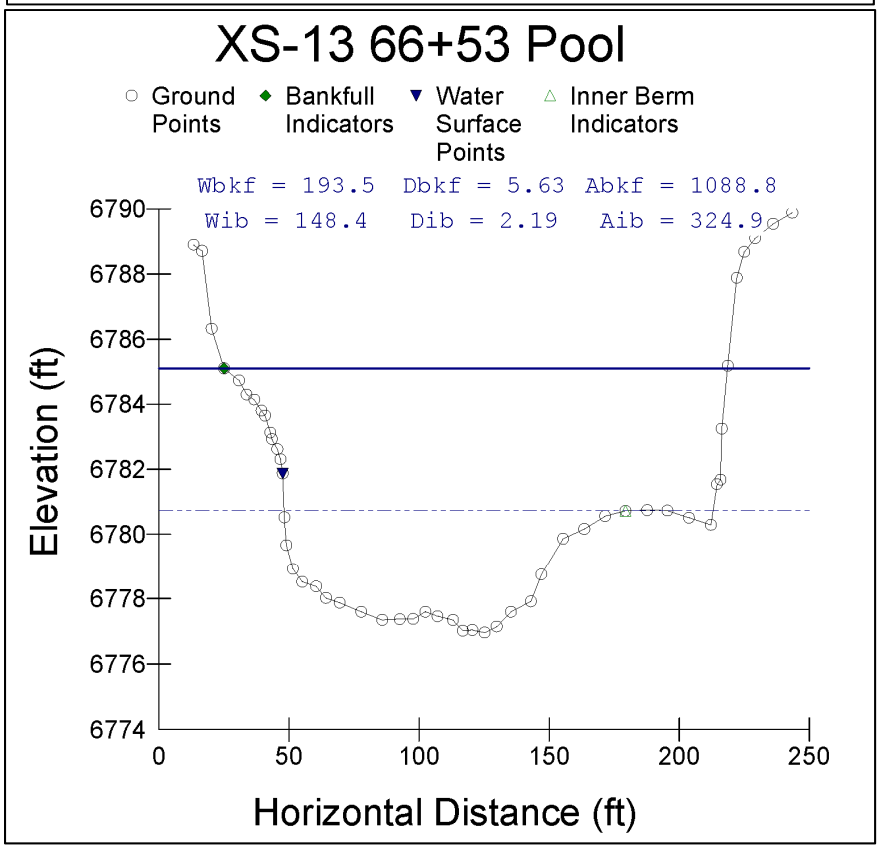

XS-8 50+58 Riffle
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 307 Dbkf = 3.69 Abkf = 1132.2
Wib = 225.5 Dib = 1.62 Aib = 366.1
Elevation (ft)
6800
6798
6796
6794
6792
6790
6788
6786
6784
6782
6780
6778
6776
0
100
200
300
400
500
600
700
800
900
Horizontal Distance (ft)

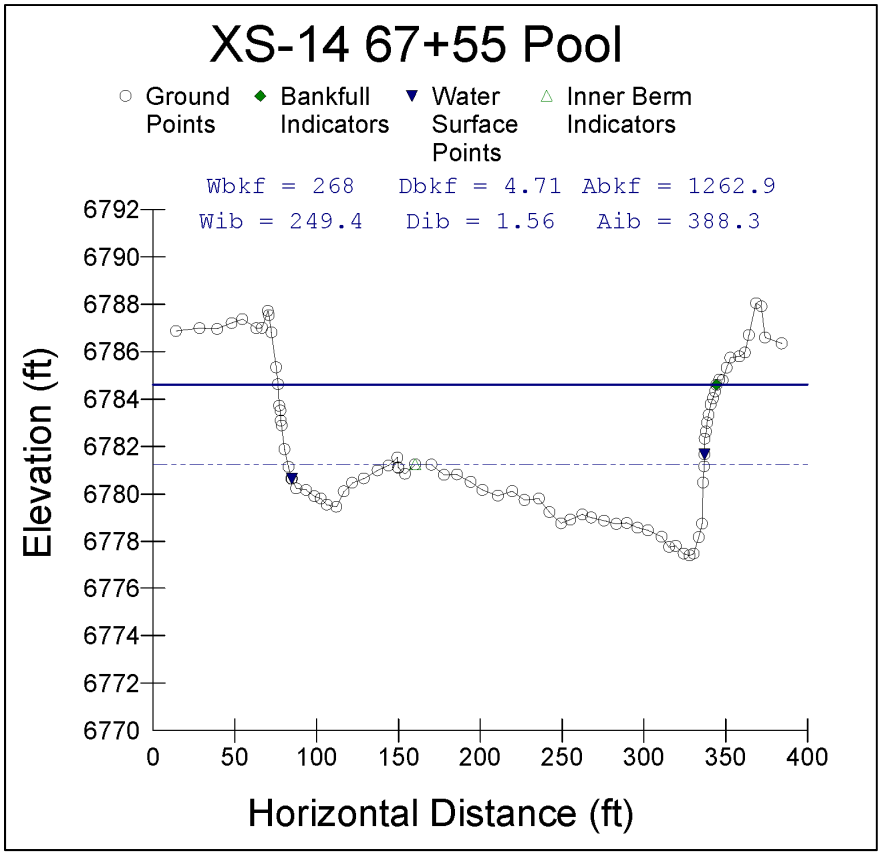

XS-9 56+40 Run
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 347.6 Dbkf = 3.24 Abkf = 1125.8
Elevation (ft)
6794
6792
6790
6788
6786
6784
6782
6780
6778
6776
6774
0
50
100
150
200
250
300
350
400
450
500
550
Horizontal Distance (ft)

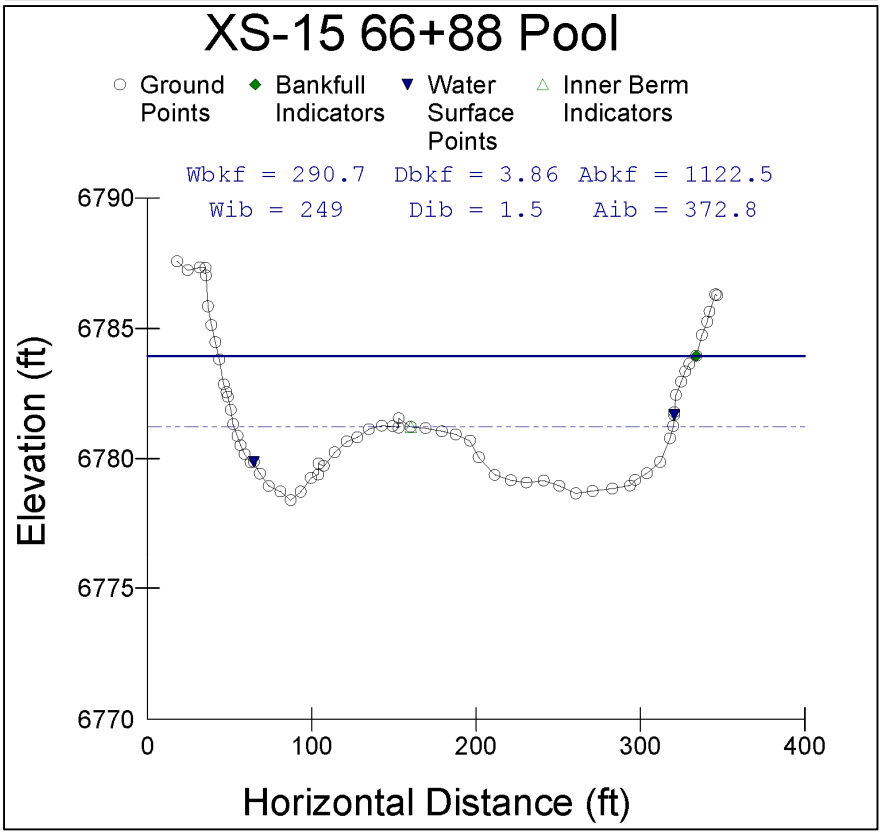

XS-10 59+67 Pool
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 192.1 Dbkf = 5.86 Abkf = 1125.7
Wib = 138.2 Dib = 1.75 Aib = 242.5
Elevation (ft)
6792
6790
6788
6786
6784
6782
6780
6778
6776
6774
0
50
100
150
200
250
300
Horizontal Distance (ft)

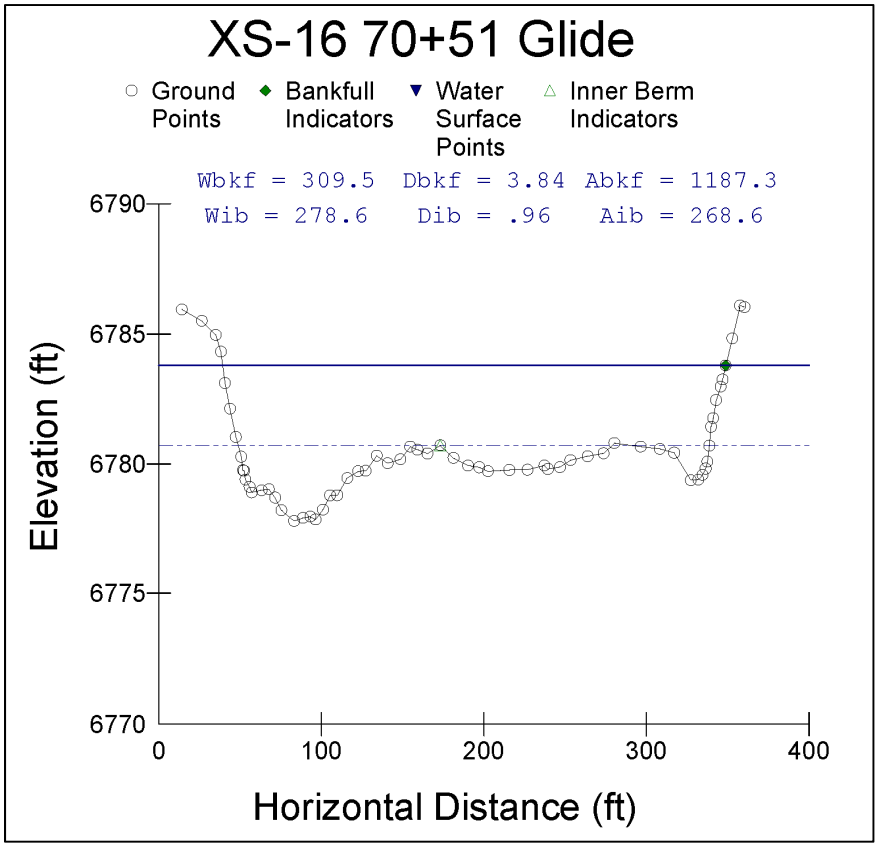

XS-11 62+38 Pool
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 196.7 Dbkf = 5.09 Abkf = 1002
Wib = 164.4 Dib = 3.09 Aib = 507.9
Elevation (ft)
6793
6791
6789
6787
6785
6783
6781
6779
6777
6775
6773
0
50
100
150
200
250
300
350
Horizontal Distance (ft)

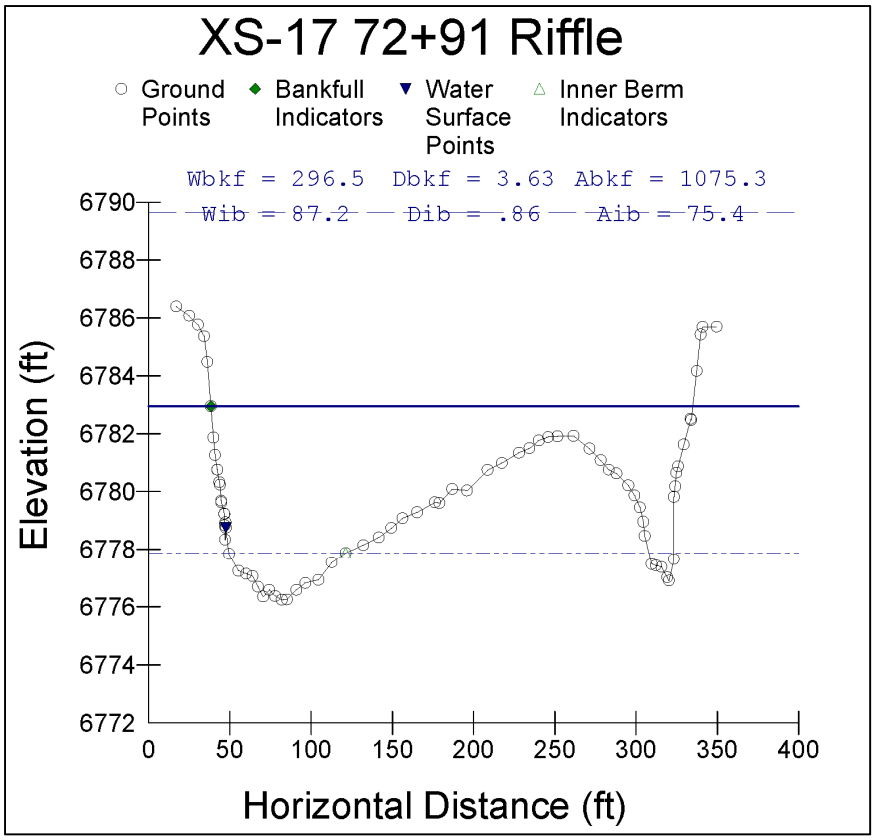

XS-12 64+81 Pool
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 222.5 Dbkf = 4.98 Abkf = 1108.2
Wib = 142 Dib = 3.7 Aib = 525.2
Elevation (ft)
6794
6792
6790
6788
6786
6784
6782
6780
6778
6776
6774
6772
6770
0
50
100
150
200
250
300
350
Horizontal Distance (ft)

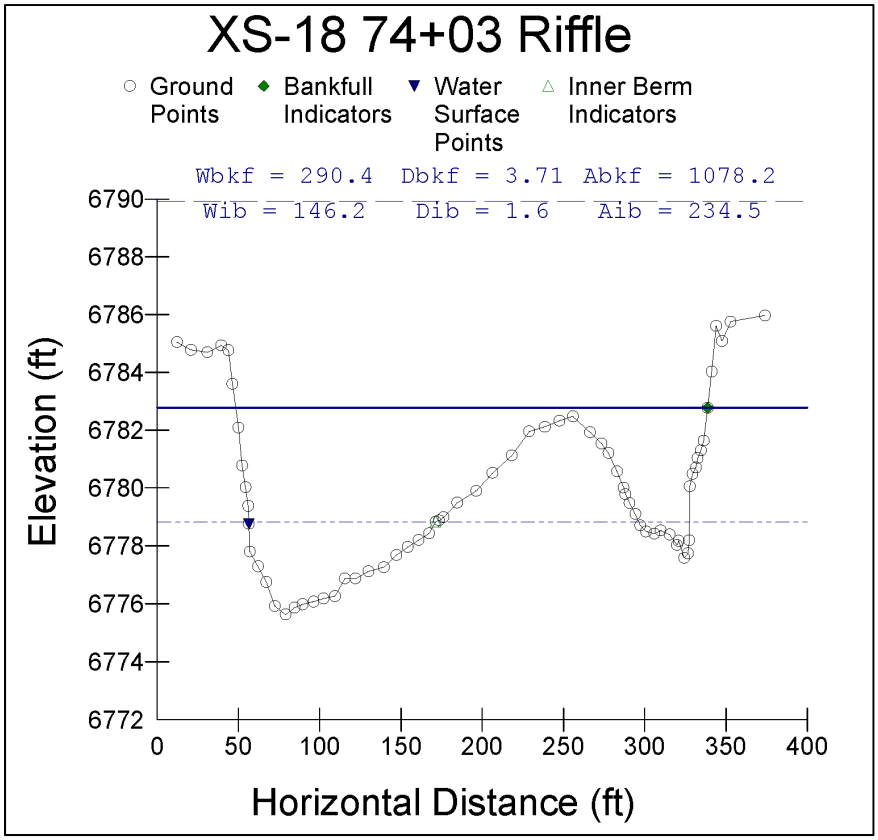

XS-13 66+53 Pool
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 193.5 Dbkf = 5.63 Abkf = 1088.8
Wib = 148.4 Dib = 2.19 Aib = 324.9
Elevation (ft)
6790
6788
6786
6784
6782
6780
6778
6776
6774
0
50
100
150
200
250
Horizontal Distance (ft)

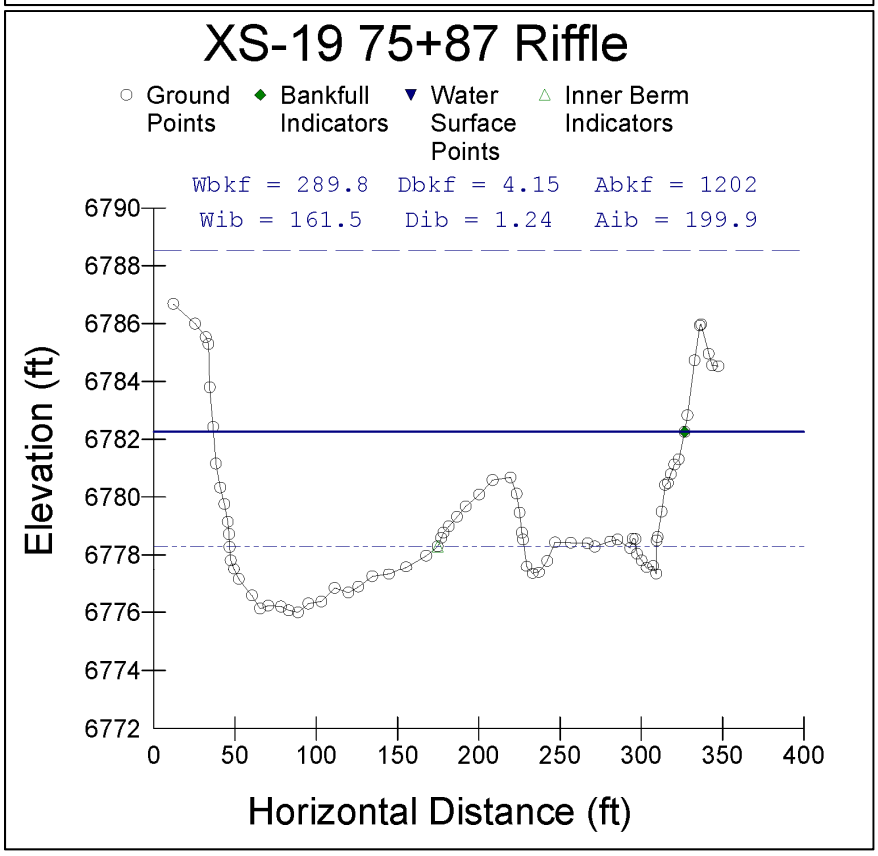

XS-14 67+55 Pool
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 268 Dbkf = 4.71 Abkf = 1262.9
Wib = 249.4 Dib = 1.56 Aib = 388.3
Elevation (ft)
6792
6790
6788
6786
6784
6782
6780
6778
6776
6774
6772
6770
0
50
100
150
200
250
300
350
400
Horizontal Distance (ft)

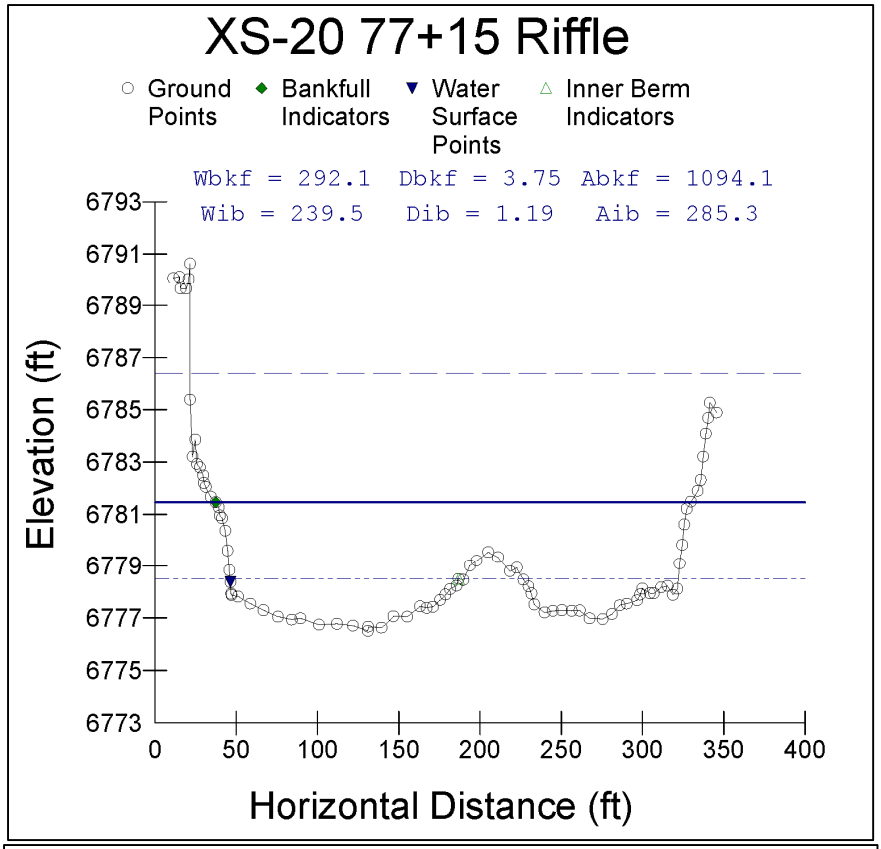

XS-15 66+88 Pool
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 290.7 Dbkf = 3.86 Abkf = 1122.5
Wib = 249 Dib = 1.5 Aib = 372.8
Elevation (ft)
6790
6785
6780
6775
6770
0
100
200
300
400
Horizontal Distance (ft)

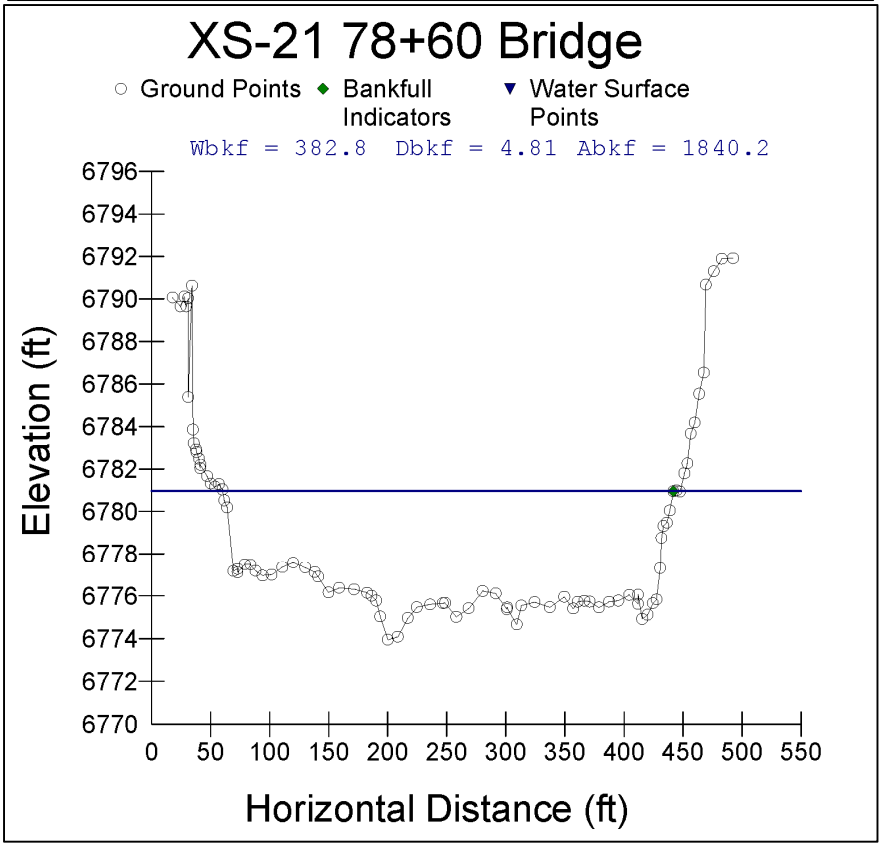

XS-16 70+51 Glide
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 309.5 Dbkf = 3.84 Abkf = 1187.3
Wib = 278.6 Dib = .96 Aib = 268.6
Elevation (ft)
6790
6785
6780
6775
6770
0
100
200
300
400
Horizontal Distance (ft)

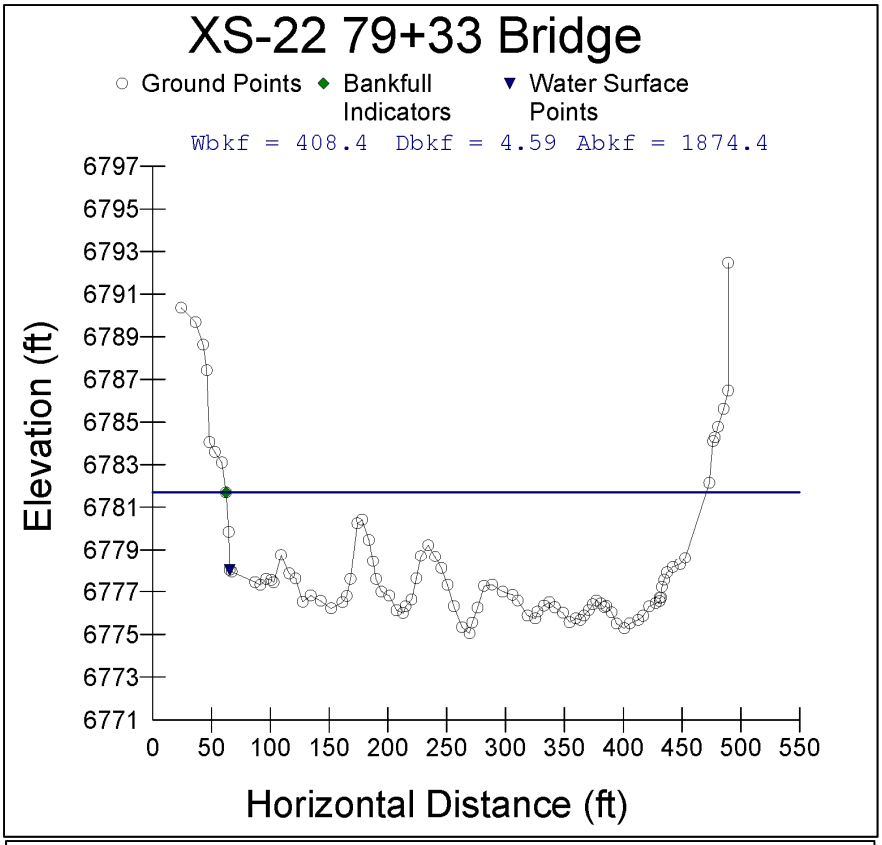

XS-17 72+91 Riffle
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 296.5 Dbkf = 3.63 Abkf = 1075.3
Wib = 87.2 Dib = .86 Aib = 75.4
Elevation (ft)
6790
6788
6786
6784
6782
6780
6778
6776
6774
6772
0
50
100
150
200
250
300
350
400
Horizontal Distance (ft)

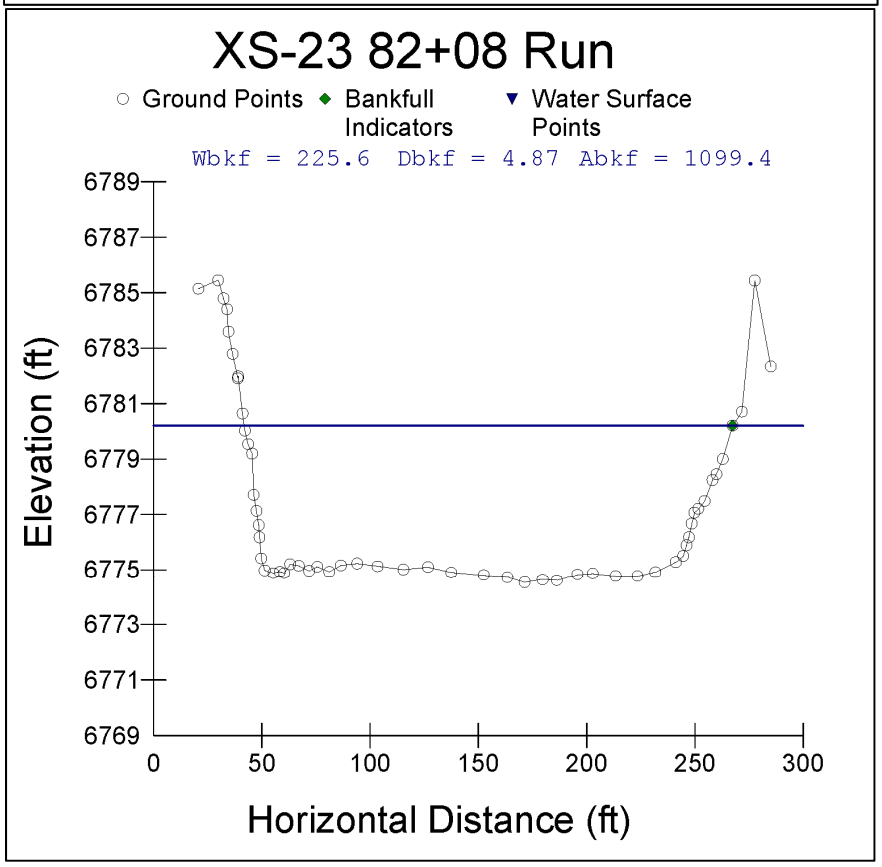

XS-18 74+03 Riffle
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 290.4 Dbkf = 3.71 Abkf = 1078.2
Wib = 146.2 Dib = 1.6 Aib = 234.5
Elevation (ft)
6790
6788
6786
6784
6782
6780
6778
6776
6774
6772
0
50
100
150
200
250
300
350
400
Horizontal Distance (ft)


XS-19 75+87 Riffle
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 289.8 Dbkf = 4.15 Abkf = 1202
Wib = 161.5 Dib = 1.24 Aib = 199.9
Elevation (ft)
6790
6788
6786
6784
6782
6780
6778
6776
6774
6772
0
50
100
150
200
250
300
350
400
Horizontal Distance (ft)


XS-20 77+15 Riffle
Ground Points
Bankfull Indicators
Water Surface Points
Inner Berm Indicators
Wbkf = 292.1 Dbkf = 3.75 Abkf = 1094.1
Wib = 239.5 Dib = 1.19 Aib = 285.3
Elevation (ft)
6793
6791
6789
6787
6785
6783
6781
6779
6777
6775
6773
0 50 100 150 200 250 300 350 400
Horizontal Distance (ft)


XS-21 78+60 Bridge
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 382.8 Dbkf = 4.81 Abkf = 1840.2
Elevation (ft)
6796
6794
6792
6790
6788
6786
6784
6782
6780
6778
6776
6774
6772
6770
0 50 100 150 200 250 300 350 400 450 500 550
Horizontal Distance (ft)


XS-22 79+33 Bridge
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 408.4 Dbkf = 4.59 Abkf = 1874.4
Elevation (ft)
6797
6795
6793
6791
6789
6787
6785
6783
6781
6779
6777
6775
6773
6771
0 50 100 150 200 250 300 350 400 450 500 550
Horizontal Distance (ft)


XS-23 82+08 Run
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 225.6 Dbkf = 4.87 Abkf = 1099.4
Elevation (ft)
6789
6787
6785
6783
6781
6779
6777
6775
6773
6771
6769
0 50 100 150 200 250 300
Horizontal Distance (ft)

APPENDIX V: FLOWSED/POWERSED RESULTS

The FLOWSED Model results representing the upstream total annual sediment yield (total suspended sediment and bedload sediment) at the Shay Bridge.

Stream: **North Platte River, Saratoga, Wyoming** Location: **Existing Condition using Upstream Sediment Meas.** Date: **6/19/14**

Observers: **BR & DB** Gage Station #: **06627000** Stream Type: **C3** Valley Type: **U-AL-FD**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (lbs/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Good/Fair" Pagosa	$y = -0.0113+1.0139x^{2.1929}$	5200	2.57	72.7
2. Suspended Sediment	"Good/Fair" Pagosa	$y = 0.0636+0.9326x^{2.4085}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1) Percentage of Time	(2) Daily Mean Discharge	(3) Mid-Ordinate	(4) Time Increment (percent)	(5) Time Increment (days)	(6) Mid-Ordinate Streamflow	(7) Dimension-less Streamflow	(8) Dimension-less Suspended Sediment Discharge	(9) Suspended Sediment Discharge	(10) Dimension-less Bedload Discharge	(11) Bedload Sediment Discharge	(12) Time Adjusted Streamflow [(5)×(6)]	(13) Suspended Sediment [(5)×(9)]	(14) Bedload Sediment [(5)×(11)]	(15) Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
100.0%	36.4													
90.0%	203.0	5.000%	10.000%	36.50	119.71	0.023	0.064	1.497	0.000	0.00	4369.4	54.64	0.00	54.64
80.0%	249.8	5.000%	10.000%	36.50	226.41	0.044	0.064	2.85	0.000	0.00	8264.0	103.96	0.00	103.96
70.0%	286.3	5.000%	10.00%	36.50	268.05	0.052	0.064	3.39	0.000	0.00	9783.8	123.56	0.00	123.56
60.0%	327.9	5.000%	10.00%	36.50	307.09	0.059	0.065	3.90	0.000	0.00	11208.8	142.18	0.00	142.18
50.0%	400.8	5.000%	10.00%	36.50	364.35	0.070	0.065	4.66	0.000	0.00	13298.6	170.05	0.00	170.05
40.0%	499.7	5.000%	10.00%	36.50	450.23	0.087	0.066	5.85	0.000	0.00	16433.2	213.45	0.00	213.45
30.0%	765.1	5.000%	10.00%	36.50	632.40	0.122	0.069	8.62	0.000	0.00	23082.4	314.59	0.00	314.59
20.0%	1540.6	5.000%	10.00%	36.50	1152.88	0.222	0.088	20.00	0.026	2.88	42080.1	729.97	105.26	835.23
10.0%	3450.8	5.000%	10.00%	36.50	2495.74	0.480	0.223	109.13	0.191	21.26	91094.5	3983.30	775.87	4759.18
5.0%	5256.900	2.500%	5.00%	18.25	4353.87	0.837	0.672	574.00	0.676	75.02	79458.1	10475.48	1369.11	11844.58
4.0%														
3.0%														
2.0%														
1.50%														
1.00%														
0.90%														
0.80%														
0.70%														
0.60%														
0.50%														
									Annual Totals:		299,073.0 (cfs) / 593,211.2 (acre-ft)	16311.2 (tons/yr)	2250.2 (tons/yr)	18561.4 (tons/yr)

The FLOWSED Model results representing the downstream total annual sediment yield (total suspended sediment and bedload sediment) at the Bridge Street Bridge.

Stream: **North Platte River, Saratoga, Wyoming** Location: **Existing Condition using Downstream Sediment Meas.** Date: **6/19/14**

Observers: **BR & DB** Gage Station #: **06627000** Stream Type: **C3** Valley Type: **U-AL-FD**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (lbs/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Good/Fair" Pagosa	$y = -0.0113+1.0139x^{2.1929}$	5200	1.8	77.3
2. Suspended Sediment	"Good/Fair" Pagosa	$y = 0.0636+0.9326x^{2.4085}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension-less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
100.0%	36.4													
90.0%	203.0	5.000%	10.000%	36.50	119.71	0.023	0.064	1.592	0.000	0.00	4369.4	58.10	0.00	58.10
80.0%	249.8	5.000%	10.000%	36.50	226.41	0.044	0.064	3.03	0.000	0.00	8264.0	110.54	0.00	110.54
70.0%	286.3	5.000%	10.00%	36.50	268.05	0.052	0.064	3.60	0.000	0.00	9783.8	131.38	0.00	131.38
60.0%	327.9	5.000%	10.00%	36.50	307.09	0.059	0.065	4.14	0.000	0.00	11208.8	151.18	0.00	151.18
50.0%	400.8	5.000%	10.00%	36.50	364.35	0.070	0.065	4.95	0.000	0.00	13298.6	180.81	0.00	180.81
40.0%	499.7	5.000%	10.00%	36.50	450.23	0.087	0.066	6.22	0.000	0.00	16433.2	226.96	0.00	226.96
30.0%	765.1	5.000%	10.00%	36.50	632.40	0.122	0.069	9.16	0.000	0.00	23082.4	334.50	0.00	334.50
20.0%	1540.6	5.000%	10.00%	36.50	1152.88	0.222	0.088	21.26	0.026	2.02	42080.1	776.15	73.73	849.88
10.0%	3450.8	5.000%	10.00%	36.50	2495.74	0.480	0.223	116.04	0.191	14.89	91094.5	4235.34	543.41	4778.75
5.0%	5256.900	2.500%	5.00%	18.25	4353.87	0.837	0.672	610.32	0.676	52.54	79458.1	11138.30	958.91	12097.20
4.0%														
3.0%														
2.0%														
1.50%														
1.00%														
0.90%														
0.80%														
0.70%														
0.60%														
0.50%														
									Annual Totals:		299,073.0 (cfs) / 593,211.2 (acre-ft)	17343.3 (tons/yr)	1576.0 (tons/yr)	18919.3 (tons/yr)

The POWERSED Model results representing the total annual sediment yield transport capacity (suspended sand sediment and bedload sediment) of the reference cross-section with a width/depth ratio of 34.

Stream: **North Platte, Existing Condition** Location: **Reference Cross-Section with 34 W/d ratio** Date: **06/19/14**

Observers: **BR & DB** Stream Type: **C3** Valley Type: **U-AL-FD** Gage Station #: **06627000**

Flow-duration curve		Calculate	Hydraulic geometry				Measure	Calculate									
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Percentage of time	Daily mean discharge	Mid-ordinate stream-flow	Area	Width	Depth	Velocity	Slope	Shear stress	Stream power	Unit power	Time increment	Time increment	Daily mean bedload transport	Daily mean suspended sand transport	Time adjusted bedload transport [(13)×(14)]	Time adjusted suspended sand transport [(13)×(15)]	Time adjusted total transport [(16)+(17)]
(%)	(cfs)	(cfs)	(ft^2)	(ft)	(ft)	(ft/s)	(ft/ft)	(lb/ft^2)	(lb/s)	(lb/ft/s)	(%)	(days)	(tons/day)	(tons/day)	(tons)	(tons)	(tons)
100.000	36.44									0.00					0.00	0.00	0.00
90.000	203.02	119.73	83.77	98.00	0.85	1.43	0.0022	0.12	16.44	0.17	10.000	36.50	0.00	0.98	0.00	35.77	35.77
80.000	249.87	226.44	124.87	102.12	1.22	1.81	0.0022	0.17	31.09	0.30	10.000	36.50	0.00	1.86	0.00	67.89	67.89
70.000	286.31	268.09	138.90	103.48	1.34	1.93	0.0022	0.18	36.80	0.36	10.000	36.50	0.00	2.22	0.00	81.03	81.03
60.000	327.95	307.13	151.43	104.69	1.45	2.03	0.0022	0.20	42.16	0.40	10.000	36.50	0.00	2.55	0.00	93.08	93.08
50.000	400.83	364.39	168.87	106.35	1.59	2.16	0.0022	0.22	50.02	0.47	10.000	36.50	0.00	3.04	0.00	110.96	110.96
40.000	499.73	450.28	193.41	108.63	1.78	2.33	0.0022	0.24	61.81	0.57	10.000	36.50	0.00	3.82	0.00	139.43	139.43
30.000	765.22	632.48	240.94	112.94	2.13	2.62	0.0022	0.29	86.83	0.77	10.000	36.50	0.00	5.53	0.00	201.85	201.85
20.000	1540.84	1153.03	357.45	122.84	2.91	3.23	0.0022	0.40	158.29	1.29	10.000	36.50	2.89	13.07	105.48	477.06	582.54
10.000	3451.28	2496.06	641.00	165.94	3.86	3.89	0.0022	0.53	342.66	2.06	10.000	36.50	21.21	71.23	774.17	2599.90	3374.07
5.000	5257.61	4354.44	930.34	182.55	5.10	4.68	0.0022	0.69	597.78	3.27	5.000	18.25	74.86	374.49	1366.20	6834.44	8200.64
4.000																	
3.000																	
2.000																	
1.500																	
1.000																	
0.900																	
0.800																	
0.700																	
										Total annual sediment yield (bedload and suspended sand bed-material load) (tons/yr):					2245.8	10641.4	12887.2

The POWERSED Model results representing the total annual sediment yield transport capacity (suspended sand sediment and bedload sediment) of the study cross-section 19 with a width/depth ratio of 69.

Stream: **North Platte, Existing Condition** Location: **Study Reach XS-19 with W/d ratio of 69** Date: **06/19/14**

Observers: **BR & DB** Stream Type: **C3** Valley Type: **U-AL-FD** Gage Station #: **06627000**

Flow-duration curve		Calculate	Hydraulic geometry				Measure	Calculate									
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Percentage of time	Daily mean discharge	Mid-ordinate stream-flow	Area	Width	Depth	Velocity	Slope	Shear stress	Stream power	Unit power	Time increment	Time increment	Daily mean bedload transport	Daily mean suspended sand transport	Time adjusted bedload transport [(13)×(14)]	Time adjusted suspended sand transport [(13)×(15)]	Time adjusted total transport [(16)+(17)]
(%)	(cfs)	(cfs)	(ft^2)	(ft)	(ft)	(ft/s)	(ft/ft)	(lb/ft^2)	(lb/s)	(lb/ft/s)	(%)	(days)	(tons/day)	(tons/day)	(tons)	(tons)	(tons)
100.000	41.24								0.00						0.00	0.00	0.00
90.000	240.67	140.95	91.40	105.08	0.87	1.54	0.0022	0.12	19.35	0.18	10.000	36.50	0.00	1.15	0.00	41.97	41.97
80.000	256.86	248.76	135.20	119.19	1.13	1.84	0.0022	0.16	34.15	0.29	10.000	36.50	0.00	2.04	0.00	74.46	74.46
70.000	287.81	272.34	143.76	121.25	1.19	1.89	0.0022	0.16	37.39	0.31	10.000	36.50	0.00	2.24	0.00	81.76	81.76
60.000	324.42	306.12	155.35	123.46	1.26	1.97	0.0022	0.17	42.02	0.34	10.000	36.50	0.00	2.52	0.00	91.98	91.98
50.000	396.46	360.44	173.18	126.78	1.37	2.08	0.0022	0.19	49.48	0.39	10.000	36.50	0.00	2.99	0.00	109.14	109.14
40.000	532.81	464.63	203.53	129.55	1.57	2.28	0.0022	0.21	63.78	0.49	10.000	36.50	0.00	3.89	0.00	141.99	141.99
30.000	724.75	628.78	246.47	132.65	1.86	2.55	0.0022	0.25	86.32	0.65	10.000	36.50	0.00	5.43	0.00	198.19	198.19
20.000	1261.06	992.90	335.10	143.97	2.33	2.96	0.0022	0.32	136.31	0.95	10.000	36.50	0.52	9.22	18.98	336.53	355.51
10.000	2629.76	1945.41	535.42	169.31	3.16	3.63	0.0022	0.43	267.07	1.58	10.000	36.50	7.21	20.75	263.17	757.38	1020.55
5.000	3793.16	3211.46	727.72	171.63	4.24	4.41	0.0022	0.58	440.87	2.57	5.000	18.25	48.56	41.10	886.22	750.08	1636.30
4.000																	
3.000																	
2.000																	

Notes:

CELL 1	1168.4	2633.7	3802.0
CELL 2	104.0	553.0	657.0
Total annual sediment yield (bedload and suspended sand bed-material load) (tons/yr):	1272.4	3186.7	4459.0
Reference W/d ratio of 34 total annual sediment comparative reach (tons/yr):	2246.0	10641.0	12887.0
Difference in sediment transport capacity (tons/yr) (+ or -):	-973.6	-7454.3	-8428.0
Stability evaluation: Aggradation, Degradation or Stable:	Aggradation		

The POWERSED Model results representing the total annual sediment yield transport capacity (suspended sand sediment and bedload sediment) of the study cross-section 3 with a width/depth ratio of 106.

Stream: **North Platte, Existing Condition** Location: **Study Reach XS-3 with W/d ratio of 106** Date: **06/19/14**

Observers: **BR & DB** Stream Type: **C3** Valley Type: **U-AL-FD** Gage Station #: **06627000**

Flow-duration curve		Calculate	Hydraulic geometry				Measure	Calculate									
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Percentage of time	Daily mean discharge	Mid-ordinate stream-flow	Area	Width	Depth	Velocity	Slope	Shear stress	Stream power	Unit power	Time increment	Time increment	Daily mean bedload transport	Daily mean suspended sand transport	Time adjusted bedload transport [(13)×(14)]	Time adjusted suspended sand transport [(13)×(15)]	Time adjusted total transport [(16)+(17)]
(%)	(cfs)	(cfs)	(ft^2)	(ft)	(ft)	(ft/s)	(ft/ft)	(lb/ft^2)	(lb/s)	(lb/ft/s)	(%)	(days)	(tons/day)	(tons/day)	(tons)	(tons)	(tons)
100.000	38.71								0.00						0.00	0.00	0.00
90.000	206.40	122.56	68.17	65.40	1.04	1.80	0.0022	0.14	16.82	0.26	10.000	36.50	0.00	1.01	0.00	36.87	36.87
80.000	232.65	219.53	100.11	71.09	1.41	2.19	0.0022	0.19	30.14	0.42	10.000	36.50	0.00	1.83	0.00	66.80	66.80
70.000	257.71	245.18	107.61	72.12	1.49	2.28	0.0022	0.20	33.66	0.47	10.000	36.50	0.00	2.05	0.00	74.82	74.82
60.000	289.23	273.47	115.60	73.21	1.58	2.36	0.0022	0.22	37.54	0.51	10.000	36.50	0.00	2.30	0.00	83.95	83.95
50.000	344.62	316.93	127.43	74.78	1.70	2.49	0.0022	0.23	43.51	0.58	10.000	36.50	0.00	2.70	0.00	98.55	98.55
40.000	415.74	380.18	144.81	78.31	1.85	2.63	0.0022	0.25	52.19	0.67	10.000	36.50	0.00	3.31	0.00	120.81	120.81
30.000	619.93	517.84	181.85	86.98	2.09	2.85	0.0022	0.28	71.09	0.82	10.000	36.50	0.13	4.67	4.75	170.45	175.20
20.000	1048.18	834.06	279.30	124.46	2.24	2.99	0.0022	0.31	114.50	0.92	10.000	36.50	0.39	7.70	14.24	281.05	295.29
10.000	2666.73	1857.45	521.12	178.06	2.93	3.56	0.0022	0.40	254.99	1.43	10.000	36.50	4.67	19.21	170.45	701.17	871.62
5.000	3486.18	3076.45	723.85	190.00	3.81	4.25	0.0022	0.52	422.34	2.22	5.000	18.25	28.21	37.05	514.83	676.16	1190.99
4.000																	
3.000																	
2.000																	

Notes:

CELL 2	704.2	2356.7	3060.9
CELL 1	375.9	663.9	1039.8
CELL 3	2.4	213.2	215.6
Total annual sediment yield (bedload and suspended sand bed-material load) (tons/yr):	**1082.5**	**3233.8**	**4316.3**
Reference W/d ratio of 34 total annual sediment comparative reach (tons/yr):	**2246.0**	**10641.0**	**12887.0**
Difference in sediment transport capacity (tons/yr) (+ or -):	**-1163.5**	**-7407.2**	**-8570.7**
Stability evaluation: Aggradation, Degradation or Stable:	**Aggradation**		

APPENDIX VI: TROUT FISHERY LIMITING FACTORS

North Platte River, Saratoga Wyoming

Trout Fishery Limiting Factor Analysis

Observation of James M. Nankervis: Fishery Biologist

April 2014

In early April 2014, an estimate of potential limiting factors relative to the trout fishery was conducted on the North Platte River in Saratoga, Wyoming. The town of Saratoga is proposing to do a river restoration of the North Platte River through town and is looking at way to improve/enhance the fishery as well as the geomorphic function of the river. Discharge in the river at the time of the 2-day site visit was about 1,500 ft^3/s, typical of the flows for early April relative to the historical gage records (1903-1970 USGS Gage No. 06627000).

Background

The North Platte River from the Colorado-Wyoming border to the confluence with Sage Creek, downstream from Saratoga, is classified as a "Blue-Ribbon" trout fishery and has been managed for wild trout by the Wyoming Game and Fish since the early 1980's. This would indicate that the general needs (spawning, rearing, adult and over-wintering habitat) of the trout fishery are being met, over time, and that the free-flowing nature of this section of river and the connectivity with its tributaries offset any temporary water quality and quantity issues. Published population estimates range from 2,000 to 4,000 catchable trout per mile, certainly enough fish to excite any angler. However, with any population estimate it is important to remember that each mile of river is not equivalent to the next and that wild trout populations fluctuate as a function of the variability in abiotic and bioctic factors that influence spawning and recruitment success on an annual basis.

Observations

Overall trout habitat is not bad. The banks are in pretty good shape with a couple of notable exceptions and the bed substrate is a good heterogeneous mixture of gravel and cobbles which favors a diverse and robust benthic community. Riparian vegetation cover varies throughout the reach from just grass to a mixed canopy of cottonwood and willow. The mixed canopy, especially on the left (west) bank tempers the thermal input in the summer months and casts long, irregular shadows that provide excellent overhead cover for trout during these periods.

Saratoga's infrastructure (bridges and utilities) has influenced sediment transport capacity of the city reach. The many long, broad transverse and mid-channel bars observed within the reach are an indication of reduced sediment transport capacity which can exacerbate bank erosion and reduce available pool habitat, particularly important for adult and over-wintering habitat. The watershed area above Saratoga is 2840 square miles with thousands of stream miles contributing to the sediment load at Saratoga. Improving the capacity to transport delivered

sediment, while reducing bank erosion from within the reach should be a priority for any restoration effort.

The quality of the fishery within the proposed restoration reach is dependent on the free-flowing nature of the North Platte River and its tributaries. Human actions and natural disturbances within the basin can negatively or positively affect the fishery, but as long as the continuity and connectivity of the system is maintained, the resiliency of the fishery to remain viable throughout will prove to be a valuable asset to Saratoga's long term economy and quality of life.

Recommendations

1) Reduce bank erosion from locations within reach that contribute inordinate amounts of sediment. Use toe-wood where possible and rock vanes when necessary. Both provide excellent, natural looking geomorphic control and enhance trout habitat at the same time. Where possible, encourage/plant more woody vegetation. A mixed canopy (tree/shrub/grass-forb) acts as natural bank revetment and provides near-bank overhead cover, as well as an allochthonus source of high quality carbon (leaf) material. The mixed canopy also provides a substrate for a more diverse terrestrial arthropod community that supplements the aquatic derived food supply for trout in the summer months.

2) Improve connectivity, upstream and downstream, during low flow periods (reduce width/depth ratio). The North Platte River's wild trout fishery is dependent on ingress and egress as seasons and life histories dictate. During low flow periods broad shallow waters between pool habitats are a thermal issue and lack of cover make trout more susceptible to terrestrial predation (bird and mammal).

3) Increase pool volume and depth. Sediment aggradation has reduced adult and over-wintering pool habitats within the city reach. Increasing pool volume will improve trout holding capacity and increased pool depth will provide cover and thermal refugia during droughty periods which will encourage more adult and sub-adult trout to take up residence. Correctly designing the plan, profile and dimension of the river can insure proper pool function and reduce likelihood of pool volume/depth loss from sediment accumulation.

James M. Nankervis

Blue Mountain Consultants, LLC