Ozarks Environmental and Water Resources Institute (OEWRI)

Geomorphic Assessment of Galloway Branch in Sequiota Park, Springfield, Missouri

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Project Scope

Olsson Associates (OA) contracted the Ozarks Environmental and Water Resources Institute (OEWRI) at Missouri State University to complete a geomorphic assessment of Galloway Branch in Sequiota Park. Sequiota Park is owned and operated by the City of Springfield in Missouri. A geomorphic assessment generally involves the collection and interpretation of channel topography (channel profile and section surveys), boundary conditions (bed and bank substrate), and disturbance indicators (e.g. bank erosion, bed scour, bar form) to support the planning and design phases for channel improvement and restoration projects.

Galloway Branch (6.8 mi^2) drains the Springfield Plateau which is mainly composed of horizontally-bedded limestone with frequent karst features such as sink holes, caves, and springs. It is an urban watershed with 52% urban area above the project reach. The stream heads in east Springfield near Sunshine Street at 1,380 fasl and enters the James River at Lake Springfield 4.6 mi below the project reach at 1,150 fasl. The GPS coordinates of benchmarks and key locations identified in this study are in Table 1. The surface drainage area at the project reach is about 5 mi^2. Presently, Galloway Branch flows through a channelized segment within the park that is confined between two vertical concrete and/or stone walls to an elevation several feet above the normal floodplain stage. In many places, the channel flows over exposed bedrock or nearly so with only a veneer of gravel on the bed. Lone Pine Road runs along the west side of the park and Sequiota Park pond is located immediately to the east of the project reach. The pond was formed by the impoundment of spring flow from Sequita Cave spring for the purpose of creating a trout hatchery in the early 1900s. Pond water exits over a spillway and joins Galloway Branch at the downstream end of the project reach near station “0”.

The City of Springfield wants to improve the stability, aesthetics, and public use of the stream corridor in the park and better connect the channel flows to floodplain areas. Olsson Associates asked OEWRI to address three questions:

1) What is the typical channel form of the upstream adjacent and relatively natural channel reach?

2) How does reference reach compare to project reach?

3) What would be an acceptable meander belt or streamway width for this type of stream?

Procedures

Two OEWRI geomorphologists (Pavlowsky and Marc Owen) and their crew visited the study site on October 15 and 16, 2008 and again on April 7, 2009 to perform the field work necessary to complete the assessment. Geomorphic field and analytical work consisted of:

1. A field survey of the longitudinal thalweg, "bankfull", and low terrace profiles. This will be used to determine riffle-pool spacing and shelf heights and slopes.

2. Cross-sections at several typical locations will be surveyed to determine the reference channel size for use in geomorphic-hydraulic analysis and to design restored channel. The terminology used for channel morphology is described in Figure 17.

3. Pebble counts and visual estimates of the bed material in the active channel is used to understand the size of the bed material present for transport and the distribution of material over the bed for roughness and sediment transport estimates, if required.

4. Assessment of bank material composition and erodibility by observations of vegetation cover, bank angle, stratigraphy, and lithology of bank deposits or materials.

5. Evaluation of the geomorphic stability and hydrologic connectivity of the Sequiota Cave branch and spillway flow in relation to the project reach on Galloway Branch.

6. A photograph log of the project site is included at the end of the report.

Results

<u>(1) Reference Reach Morphology.</u> Two reference reaches (A & B) were surveyed to help better understand the typical channel conditions that might be expected in the project area if channelization and other disturbances were not present (Figure 1; Photo 18, 19 of A; Photo 20, 21, 22 of B). The reference reaches are located immediately upstream of Sequiota Park on either side of the Lacuna bridge-crossing. The culvert bridge at Lacuna has a high floor that acts as a bed obstacle which effectively disconnects the beds of the two reference reaches until stages approach bankfull. In addition, the bridge collects large woody debris on the upstream side and can block flow to a degree. Apparently, bed load can move through the culvert easily at higher flows since ample channel bed deposits are located immediately below the bridge. Longitudinal profiles for reaches A and B have a riffle spacing of 122 ft (6x Wbf), residual pool depth of 1.2 ft, and reach slopes between 0.004 to 0.008 (Tables 2 & 4; Figures 1 & 2). The channel is bedrock-controlled with low sinuosity (<1.1). For the most part, these are losing stream sections that rarely contain baseflow, although water will collect in pools in low

elevation areas over impervious bedrock and in the scoured channel section immediately above the bridge in reference reach A.

Galloway Branch upstream of the project area has a bankfull width of 19 ft +/- 1.5 ft and mean bankfull depth of 1.1 ft +/- 0.5 ft (+/- indicates the approx. one standard deviation range) (Table 3). In this study, the bankfull stage is determined at the top limit of bedload transport as indicated on high bar surfaces or at bank cut lines at similar elevations (Figure 17). These channels are confined by relatively high banks and have Rosgen entrenchment ratios near 1.2. Total channel width is 30 ft +/- 3 ft, mean depth is about 2.9 ft +/- and maximum depth is about 4.7 ft +/- 0.5 ft. Bankfull cross-section area is about 23 ft^2 and the total channel area is about four times larger. The bankfull discharge in this section of Galloway Branch is about 80 cfs as determined by morphologic indicators in the field (Table 4). Cross-section surveys for Reach A and B are shown in Figures 6-16.

Channels in the Springfield area are usually bedrock-controlled to some extent with thalwag beds on or close to bedrock. In the reference reaches, bedrock is exposed on 30-50% of the channel bed. Where gravel is deposited over bedrock areas on the channel bed, median (D50) bed particle diameter is variable with the D50 ranging from about 15 mm in a previous survey up to 45 mm in a pebble count in April 2009. The D84 has remained relatively consistent over time and ranged from 59 to 70 mm. The maximum mobile clast size ranges from 206 to 228 mm in the reference reach (Tables 5 & 6).

Bank materials are largely composed of cohesive materials of silt loam to silty clay loam in texture. In some places the banks are composite in form with finer overbank deposits over gravelly channel deposits. Tree roots and thick ground cover protects the bank from erosion in some places. However, upper banks angles can be steep and near vertical on bends or where obstacles deflect flow toward the bank. Moreover, the frequent occurrence of scour on exposed earth banks reflects the urban hydrology of the watershed.

Sediment mobility analysis indicates that the reference channel can transport the sizes of material observed on the bed (Table 7). Calculations at bankfull stage result in velocities from 3.3 to 3.9 ft/s (Table 4) and mean boundary shear stress values from 0.32 to 0.48 lb/ft (Table 7). In general, predicted critical bed material diameters bracket the median size on the bed and the upper mobility limit equals or slightly exceeds the field measured D84 (Table 7). This finding is supported by field observations of scour zones separated by accumulations of gravel and cobble in riffles or bars. The sediment budget is slightly negative throughout the reference reach and bedrock resistance is maintaining channel stability to a large degree. The sediment deposited in the reach is derived locally by erosion of lower bank deposits (larger cobbles or bedrock blocks), transported from the upper watershed during peak floods (coarse gravel and cobble) or deposited on the falling limb of flood waves (finer gravels). While sediment transport

rates are unknown, gravel-sized sediment is probably easily moved through the reference reach and delivered to the project reach.

(2) Similarity of Project Channel to Reference Reach. The project was surveyed in a similar manner as the reference reach (Table 8; Figure 5a). It was difficult to identify bankfull stage due to channelization and wall construction. Therefore, the active channel width was measured between obvious low channel benches or between vertical walls (Figure 5c). The bank heights described refer to “total bank height” or the point where the channel would spread out over the valley floor, excluding the effects of the walls (Figure 5c). At some places in the study reach, incipient floodplains are forming at about 1 to 2 ft maximum depth by fine-grained deposition at relatively wide sections or in pocket areas behind obstacles.

Overall, the reference reach is similar to project reach. The project reach has a sinuosity of <1.10 and overall slope of 0.004 with local bedrock-controlled areas being steeper at 0.012 (Figure 5a). The active or bankfull width is similar or slightly smaller compared to the reference reach and averages 16 ft, typically ranging from 13 to 19 ft. This is expected since the channel width of the project reach is constricted due to influence of past wall construction to channelize the stream. The total channel bank height is a bit larger than the reference reach, again due to the influence of the wall constriction. Total bank height averages 5 ft and ranges from 4 to 7 ft in the project reach. The walls confine flood flows that would normally go over the bank tops occurring in the reference reach.

The bed substrate of the project reach is generally similar to the reference reach. Visual estimates of bed material size produce a size distribution of 30% gravel, 50% cobble, and 20% bedrock (Figure 5b). However, much of the bed gravel is deposited thinly over bedrock so that the effective bedrock substrate covers more than 50% of the project reach. In several places in the project reach, bedrock exposures consist of exposed karst pinnacles up to three feet in height, act as significant obstacles to flow, and contribute to high levels of bed roughness. Any modifications to the existing channel must take into consideration the influence of the bedrock on channel processes as well as construction costs. The project reach represents a severe example of uneven bedrock substrate even for the Ozarks.

The maximum mobile clast size in the project reach increases in the middle segment of the where slope increases as the channel comes in contact with the bedrock pinnacles (Tables 5a & 5b). This may be due to two main factors. First, the middle segment of the project reach is steeper than the reference reach due to local bedrock influence and therefore can move and imbricate larger clasts. Second, larger clasts are being supplied to the channel from two local sources: eroding foundation blocks from failing walls and fracturing of exposed bedrock. These larger clast sizes may give a better indicator of the energy of the stream and size of material required to stabilize the channel under the existing slope and flow conditions.

Bank conditions in the project reach have been altered by channelization, multiple phases of wall construction, and backfilling with earth and construction debris. Any plan to widen the channel and create a floodplain should consider the degree of excavation required and the nature of the debris to be removed. As mentioned above, where fine-grained floodplain benches have been allowed to form in these modified channels, they range in height off the bed from 1 to 2+ ft.

(3) Subreach Classification for the Project Reach. While the reference reaches are generally similar to the project reach, there are differences in channel slope and substrate of geomorphic importance within the project reach. Three subreaches have been identified in the project reach (Table 9; Figure 5). These are numbered in relation to the upstream direction, but will be described in downstream order below

Subreach #3- This reach receives water and sediment directly from reference reach B and runs from stations 1,025 to 1,400 ft on the MSU longitudinal profile. It has a slope of about 0.2% and active width of 15 ft. Bedrock in this reach is relatively smooth and covered by a thin veneer or patches of gravel and cobble material (Photo 1, 2, 3, 25). The D50 for this reach ranges from 20 to 50 mm, D84 from 60 to 90 mm, and maximum mobile clast size from 118 to 222 mm (Photo 23). Older channel walls are being undercut and failing in most places (Photo 4, 24, 26).

Subreach #2- This reach is severely affected by bedrock control, rough bedrock pinnacles are exposed throughout and its slope is 3 to 5 times greater than subreaches 1 and 2 (Table 9; Photo 6, 7, 9, 18, 27). Subreach #2 runs from stations 600 to 1,025 ft on the MSU longitudinal profile. It has a slope of about 1% and active width of 16 ft. Bedrock in this reach is relatively rough and pinnacle-shaped with depressions and pits trapping patches of gravel and cobble material (Photo 5, 8, 28, 29). Substrate size is variable and controlled by bed roughness, falling limb trapping, and local source inputs. Maximum mobile clast diameter is >300mm.

Flows in subreach 2 will achieve higher velocities and shear stress due to increased bed slope. In addition, increased flow turbulence due to pinnacle obstruction is common in this subreach. Therefore, channel designs for this reach should address this situation in contrast to the lower slope condition of subreaches 1 and 3. Larger diameter rock and a more confined channel cross-section will probably be required in subreach 2.

Subreach #1- The reach runs from stations 100 to 600 ft on the MSU longitudinal profile. It has a slope of about 0.3% and active width of 15 ft. Bedrock in this reach is relatively smooth with some rough spots and and covered by a thin veneer or patches of gravel and cobble material (Photo 10, 11, 12, 13, 14, 15, 16, 17). The D50 for this reach is about 20 mm, D84 about 60 mm,

and maximum mobile clast diameter of 326 mm (Photo 31). Older channel walls are being undercut and failing in some places and anthropogenic debris is entering the channel from fill bank erosion (Photo 30). During dry periods, water is observed to enter the channel in this section from under the east wall by pond seepage through the earth berm.

(4) <u>Meanderbelt Width for Long-term Stability.</u> The combined width of the active or bankfull channel and adjacent floodplain areas indicate the ability of the channel to both (i) freely migrate and form an active floodplain, and (ii) store and dissipate energy of overbank floods. This area is typically referred to as the meander belt and provides the flood capacity of the natural channel. Streams of the same size as in the study area and around the City of Springfield in general do not typically migrate laterally very fast, if at all. Often channels are found to maintain the same position for 50 years or longer. Possible reasons for this behavior include: (i) strong resistant influence of bedrock control and confined valleys and (ii) occurrence of relatively resistant banks due to clayey banks and root protection. In Ozarks streams where lateral migration rates are relatively low, channels form a more entrenched morphology since floodplains are lacking or only represented by narrow benches. In this case, the" total channel" is used to describe the entire channel and its flood discharge capacity at the valley floor elevation (Figure 17).

For this project, it is planned for toe and low bank stabilization to be used to lock the channel location in place. However, if the channel is allowed to migrate freely within the valley, additional accommodation area must be included in existing valley floor or floodplain areas. The valley floor area required to provide adequate area to allow free lateral migration of the channel over time is difficult to determine since true meander belts do not occur very often in these types of Ozarks streams. Active floodplains and oxbows are not common along these streams so it is hard to evaluate the floodplain capacity required for floods or the width required for free migration of the channel. Thus, maximum top or total channel width relates more to the design flood capacity of the two-stage channel or shear stress controls and includes the total of channel, bar, and floodplain cross-section. The meander belt width required for a laterally mobile channel can be calculated using data from a geomorphic study of Ozark channels in the South Dry Sac watershed which drains northern Springfield. Horton (2003) determined that the meander amplitude for local stream channels is 2.85 x Wbf (project width of 54 ft). Adding the error term of 30% to this ratio, the ratio increases to 3.7 x Wbf. Thus, if the channel were allowed to meander freely in the project area, it would require about 70 feet of valley floor width or about 2x the total channel top width of the design channel.

Conclusions

(1) Channel dimensions: The new project reach channel should be fitted to existing slope with riffle structures spaced about 5 to 7 times bankfull width and residual pool depths of 1 to 1.5 ft. A typical bankfull width would be 20 ft with a mean bankfull depth of 1 to 1.2 ft. The top channel width should range from 27 to 33 ft with a mean depth of 2.5 to 3 ft. Constructed floodplains should be at an elevation of about 2 to 3 ft off the bed, but it is common for streams of this type to have banks that are 4 to 5 ft in height. If possible, at least one wall should be removed and lower floodplain storage added along most of the project reach. This floodplain must tie in to upstream bank heights since they may be higher than the new floodplain in some places. Bank heights are relatively low at the downstream end of the project reach, and constructed floodplains will tend to be at the same height as existing banks in this area near the confluence with the Sequiota Cave tributary.

(2) Application of Reference Reach to Design Process: Due to the proximity of the reference reach to the project reach, it should be no surprise that the channels are nearly identical if the influences of wall constriction, modified banks, and rough bedrock are considered. The project reach was divided into three subreaches based on bed slope and bedrock substrate. The middle of the project reach (subreach #2) is relatively steep and rough due to exposed bedrock pinnacles with up to 3 ft of local relief in the bed. This reach will require a somewhat different channel design compared to the other subreaches due to higher flow velocities and turbulence. Larger rock and a more confined channel area may be required in subreach 2 to maintain channel stability and sediment transport in this steep reach.

(3) Top Channel and Meander Belt Width: There are very few floodplain analogs in the vicinity upon which to evaluate the most effective width of the channel bank set-backs and floodplain width. However, the reference channel and project reach are relatively entrenched inferring that adding some lower floodplain area to the channel would improve flood control and reduce flow velocities. The top channel width for this project should be around 30 ft. If additional land area is desired to buffer the channel for potential lateral migration and maximum flood capacity, then a meander belt of 60 to 80 ft is sufficient.

(4) Stability of the Sequiota Cave tributary: The short reach connecting the pond outflow to Galloway Branch is stable and resistance factors include bedrock bluffs, cobble bed material, and tree protection on the floodplain and banks. The pond water surface elevation is higher than the channel bed of Galloway Branch and some seepage comes in to the channel along the toe of the east bank from stations 50 to 350 ft. However, this process does not seem to weaken the present bank since in many cases it is armored or walled. If earthen banks are to be restored to the east side of this section of the channel, the effects of pore water pressure and sapping on bank stability should be evaluated beforehand.

Table 1. GPS and Monument Coordinates and Relative Elevations

ID	Northing (ft)	Easting (ft)	Rel. Elev. (ft)
gps1	479,484.36654	1,425,420.77302	104.54
gps2	479,308.89297	1,425,401.95985	105.40
gps3	479,067.35828	1,425,371.41374	102.21
gps4	478,776.02337	1,425,275.14269	100.12
gps5	478,632.54432	1,425,178.72011	99.70
gps6	478,530.57000	1,425,170.42200	100.00
OABM 1577	479,067.35830	1,425,371.41400	102.21
MSUBM 1	479,555.14859	1,425,440.50881	109.61
OABM 1613	478,840.72303	1,425,303.50064	99.49
MSUBM 2	478,303.09670	1,425,153.77583	100.35

Table 2. Reference Bedform Morphology

Reach	Riffle Spacing (ft)	Pool Spacing (ft)	Riffle - Pool Spacing (ft)	Max Residual Pool Depth (ft)
Reach A	132.4	107.3	66.2	1.1
Reach B	112.2	131.2	73.5	1.3
Average	122.3	119.3	69.9	1.2

Table 3. Reference Reach Cross-section Morphology

X-Section	Bankfull Width (ft)	Bankfull Max Depth (ft)	Bankfull Mean Depth (ft)	Bankfull W/D Ratio	Bankfull Area (ft2)	Total Channel Width (ft)	Total Channel Max Depth (ft)	Total Channel Mean Depth (ft)	Total Channel W/D Ratio	Total Channel Area (ft2)	Flood Prone Width (ft)	Entrench-ment Ratio
Reach A												
Riffle 1	19.35	1.34	0.89	21.74	17.22	28.21	4.17	2.76	10.22	77.86	22.96	1.19
Riffle 2	19.77	1.54	1.21	16.37	23.87	36.46	5.65	2.62	13.91	95.59	21.33	1.08
Riffle 3	21.32	1.87	1.21	17.62	25.80	35.42	4.43	2.43	14.58	86.07	26.57	1.25
Riffle 4	17.38	1.31	0.79	22.00	13.73	24.27	4.2	2.76	8.79	66.99	19.35	1.11
Reach A												
Pool 1	15.74	1.77	0.79	19.92	12.43	26.57	4.7	2.2	12.08	58.45	20.01	1.27
Pool 2	18.04	2.43	1.48	12.19	26.70	29.52	5.71	3.18	9.28	93.87	23.94	1.33
Pool 3	17.38	1.38	0.85	20.45	14.77	30.83	5.35	3.44	8.96	106.06	20.66	1.19
Reach B												
Riffle 1	19.35	2.46	1.31	14.77	25.35	29.52	5.74	3.61	8.18	106.57		
Riffle 2	21.98	2.3	1.31	16.78	28.79	24.93	3.97	2.95	8.45	73.54		
Riffle 3	20.34	1.97	1.34	15.18	27.26	29.52	4.53	3.02	9.77	89.15		
Riffle 4	18.04	2.13	1.38	13.07	24.90	27.88	4.76	3.15	8.85	87.82		
Mean Riffle (n=8)	19.69	1.87	1.18	17.19	23.36	29.53	4.68	2.91	10.34	85.45		
Mean Pool (n=3)	17.05	1.86	1.04	17.52	17.97	28.97	5.25	2.94	10.11	86.13		

Table 4. Reference Reach Channel Hydraulics

X-Section	Bankfull Width (ft)	Bankfull Mean Depth (ft)	Bankfull Area (ft2)	Slope ft/ft	Hydraulic Radius	Mannings n	Velocity ft/s	Q cfs
Reach A								
Riffle 1	19.35	0.89	17.22	0.0083	0.82	0.033	3.6	61.9
Riffle 2	19.77	1.21	23.87	0.0083	1.08	0.033	4.3	103.1
Riffle 3	21.32	1.21	25.80	0.0083	1.09	0.033	4.3	112.1
Riffle 4	17.38	0.79	13.73	0.0083	0.72	0.033	3.3	45.6
Reach A								
Pool 1	15.74	0.79	12.43	0.0083	0.72	0.033	3.3	41.1
Pool 2	18.04	1.48	26.70	0.0083	1.27	0.033	4.8	128.7
Pool 3	17.38	0.85	14.77	0.0083	0.77	0.033	3.5	51.3
Reach B								
Riffle 1	19.35	1.31	25.35	0.0043	1.15	0.033	3.3	82.5
Riffle 2	21.98	1.31	28.79	0.0043	1.17	0.033	3.3	94.6
Riffle 3	20.34	1.34	27.26	0.0043	1.18	0.033	3.3	90.2
Riffle 4	18.04	1.38	24.90	0.0043	1.20	0.033	3.3	83.0
Mean Riffle (n=8)	19.69	1.18	23.36	0.01	1.05	0.033	3.6	84.1
Mean Pool (n=3)	17.05	1.04	17.97	0.01	0.92	0.033	3.9	73.7

Table 5. Reference and Project Reach Pebble Counts (2007 & 2008)

Reach	D10 (mm)	D16 (mm)	D50 (mm)	D84 (mm)	D95 (mm)	Dmax (mm)
Reach A (n=110)						
Riffles	fines	fines	15	59	97	228
Pools	fines	fines	21	48	100	-
Reach B (n=100)						
Riffles	fines	fines	12	70	128	206

Table 6. Reference and Project Reach Pebble Counts (April 2009 Pebble Counts-mm)

Station (ft)	D10	D16	D50	D84	D95	Dmax
1,200	7	9	21	60	101	118
1,070	1	28	55	90	121	222
570	5	5	16	40	90	326
Ref B	9.5	15.2	45	60	100	208

Table 7. Reference Reach Sediment Transport

X-Section	Slope ft/ft	Hydraulic Radius	Mean Boundary Shear Stress (lb/ft)	Critical Dia 1 (mm)	Critical Dia 2 (mm)	D50 (mm)	D84 (mm)	Dmax (mm)
Reach A								
Riffle 1	0.0083	0.82	0.42	32	81	15	59	228
Riffle 2	0.0083	1.08	0.56	42	99	15	59	228
Riffle 3	0.0083	1.09	0.56	43	100	15	59	228
Riffle 4	0.0083	0.72	0.38	28	74	15	59	228
Reach A								
Pool 1	0.0083	0.72	0.37	28	73	21	48	-
Pool 2	0.0083	1.27	0.66	50	112	21	48	-
Pool 3	0.0083	0.77	0.40	30	78	21	48	-
Reach B								
Riffle 1	0.0043	1.15	0.31	23	64	12	70	206
Riffle 2	0.0043	1.17	0.31	23	65	12	70	206
Riffle 3	0.0043	1.18	0.32	24	65	12	70	206
Riffle 4	0.0043	1.20	0.32	24	66	12	70	206
Mean Riffle (n=8)	0.0063	1.05	0.40	30	77	14	65	217
Mean Pool (n=3)	0.0083	0.92	0.48	36	88	21	48	-

Table 8. Project Reach Data

Station (ft)	Width (ft)	Rt Bank Ht (ft)	Lt Bank Ht. (ft)	Water Depth (ft)
1387.4	17.1	2.5	5	
1354.6	14.1	4	5.5	
1321.8	14.4	4	6	
1289	16.1	4.5	5	
1256.2	11.2	3	2.5	
1223.4	12.5	3.5	4	
1190.6	14.1	4	3.5	
1157.8	15.1	5	5	
1125	17.7	5	8.5	
1092.2	16.4	3.5	7	
1059.4	20.3	5.5	7	
1026.6	20	5.5	7	
993.8	20.3	6	7	
961.0	18.4	5.5	7.5	
928.2	16.7	5.7	8.3	
895.4	16.1	8	9	
862.6	7.5	9	9	
829.8	13.1	8	5	
797.0	15.7	5	4.5	
764.2	18	4.5	3.5	
731.4	17.4	4	4	
698.6	15.1	4.5	4	
665.8	14.1	4.5	5	
633	13.1	4.5	5.5	
600.2	12.8	4.5	5	
567.4	13.1	5.5	5.5	
534.6	13.5	5	5.5	
501.8	16.4	4	5	
469	16.4	5	5	
436.2	15.1	4.5	4	0.8
403.4	12.1	5	5	0.8
370.6	14.1	6	5.5	1.7
337.8	12.8	7.5	5.5	0.9
305.0	17.1	7	5	0.8
272.2	17.4	6.5	3.5	1.6
239.4	20	7	2.5	0.9
206.6	18	8	2.5	0.9
173.8	16.4	6	3	0.9
141	19	5	2.5	1.1
108.2	19	2.5	2.5	0.9
75.4	15.7	2.5	2.5	0.8
42.6	24.9	3	1	0.5
0	22	2	4	1.1

Table 9. Channel Characteristics of Sub-Reaches

Sub-Reach	Station (ft)	Slope %	% Bedrock	% Cobble	% Gravel	Active Width (ft)
SR-1	100-600	0.16	8	69	23	16.8
SR-2	600-1,025	1.08	37	50	13	16
SR-3	1025-1,400	0.29	28	33	39	14.7

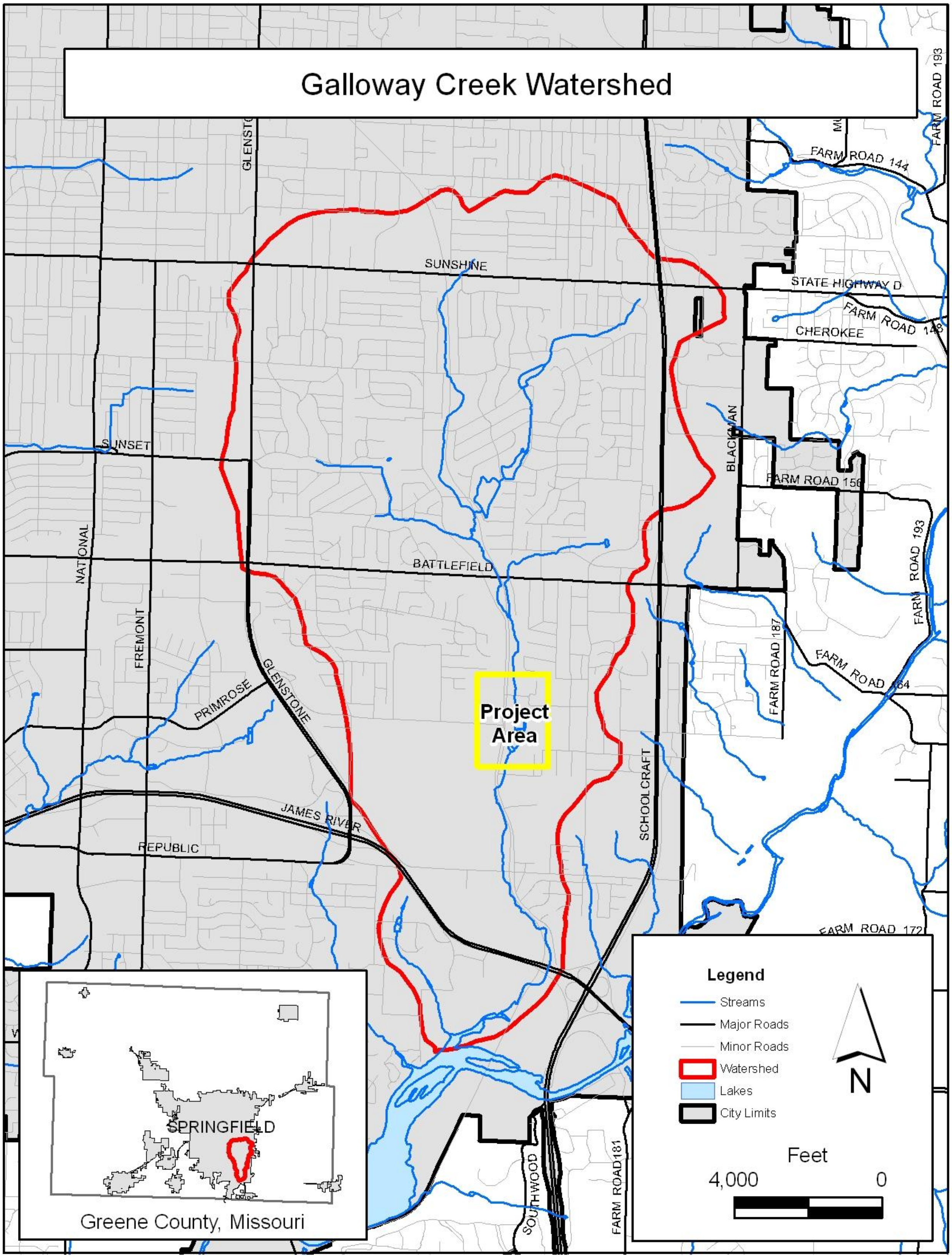

Figure 1. Project Location

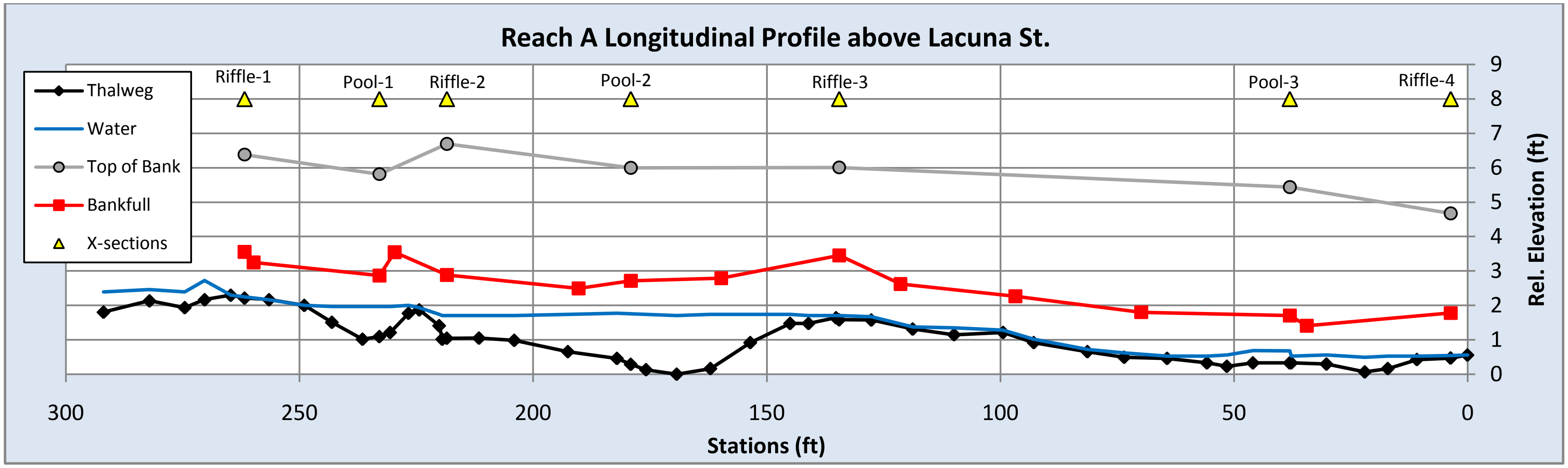

Figure 2. Reach A Longitudinal Profile

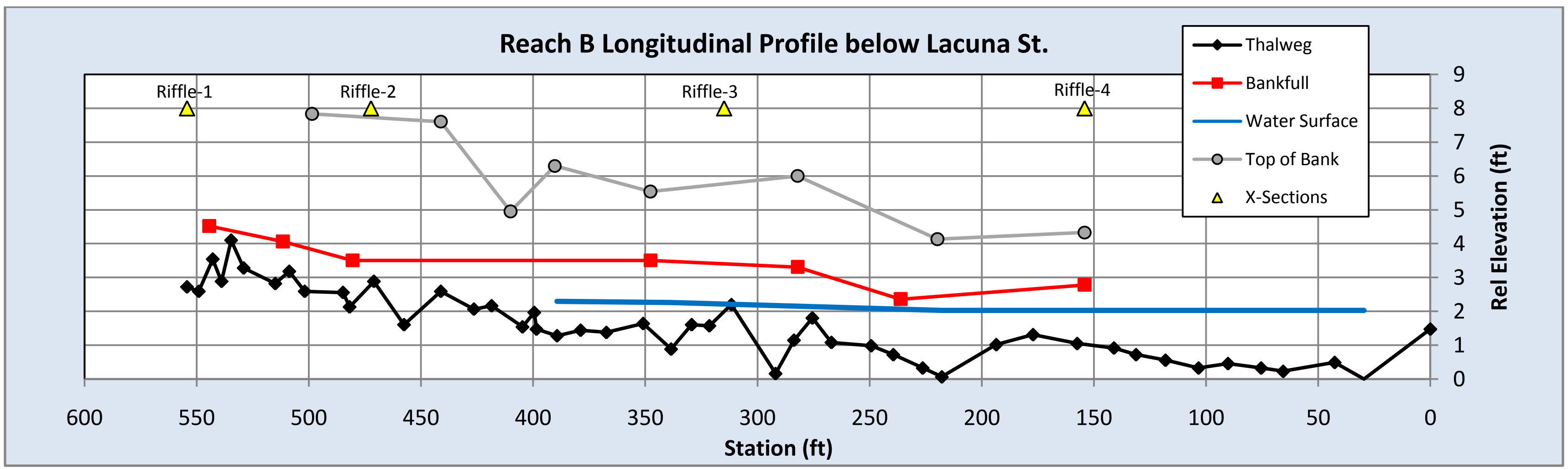

Figure 3. Reach B Longitudinal Profile

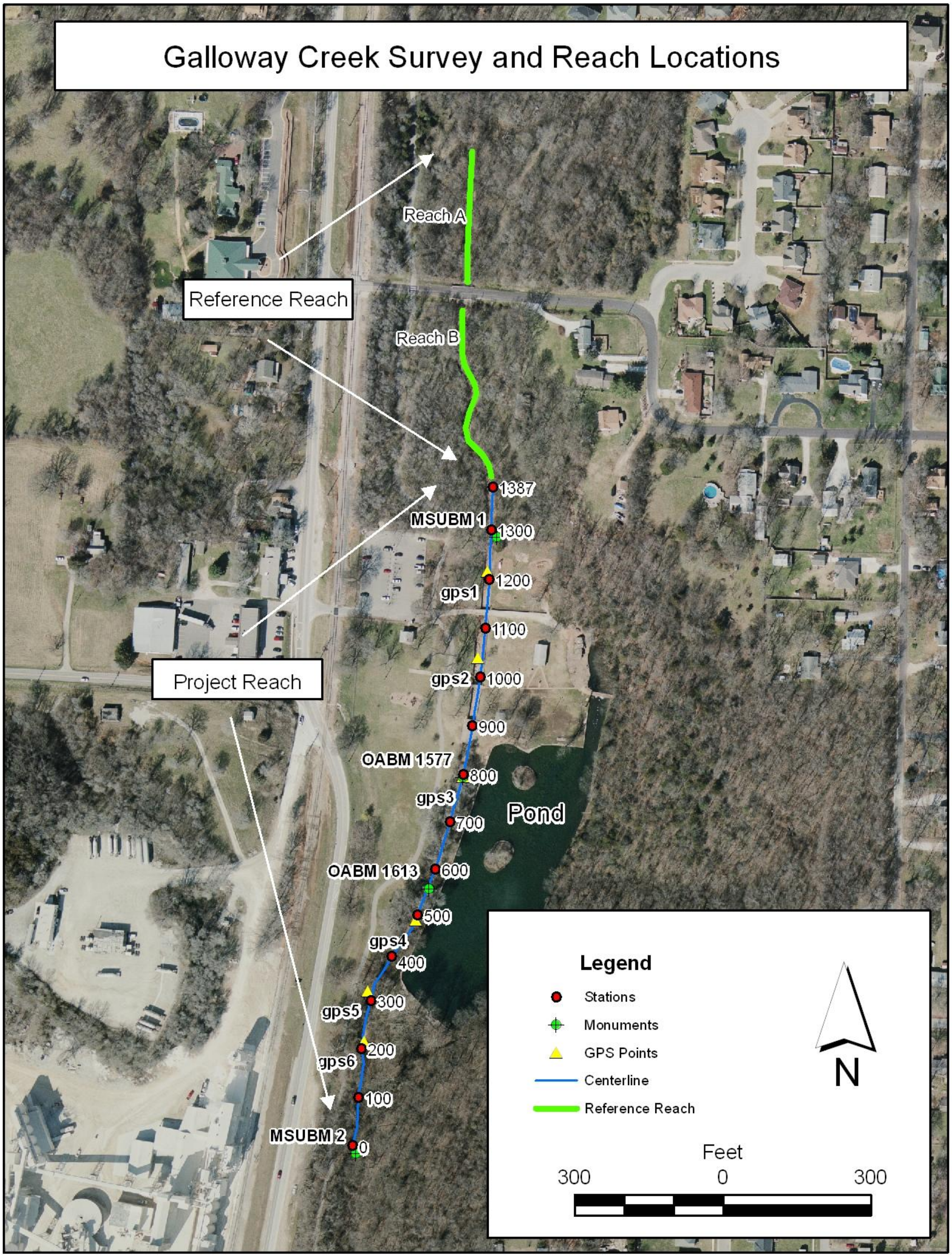

Figure 4. Project Area Survey and Reach Locations

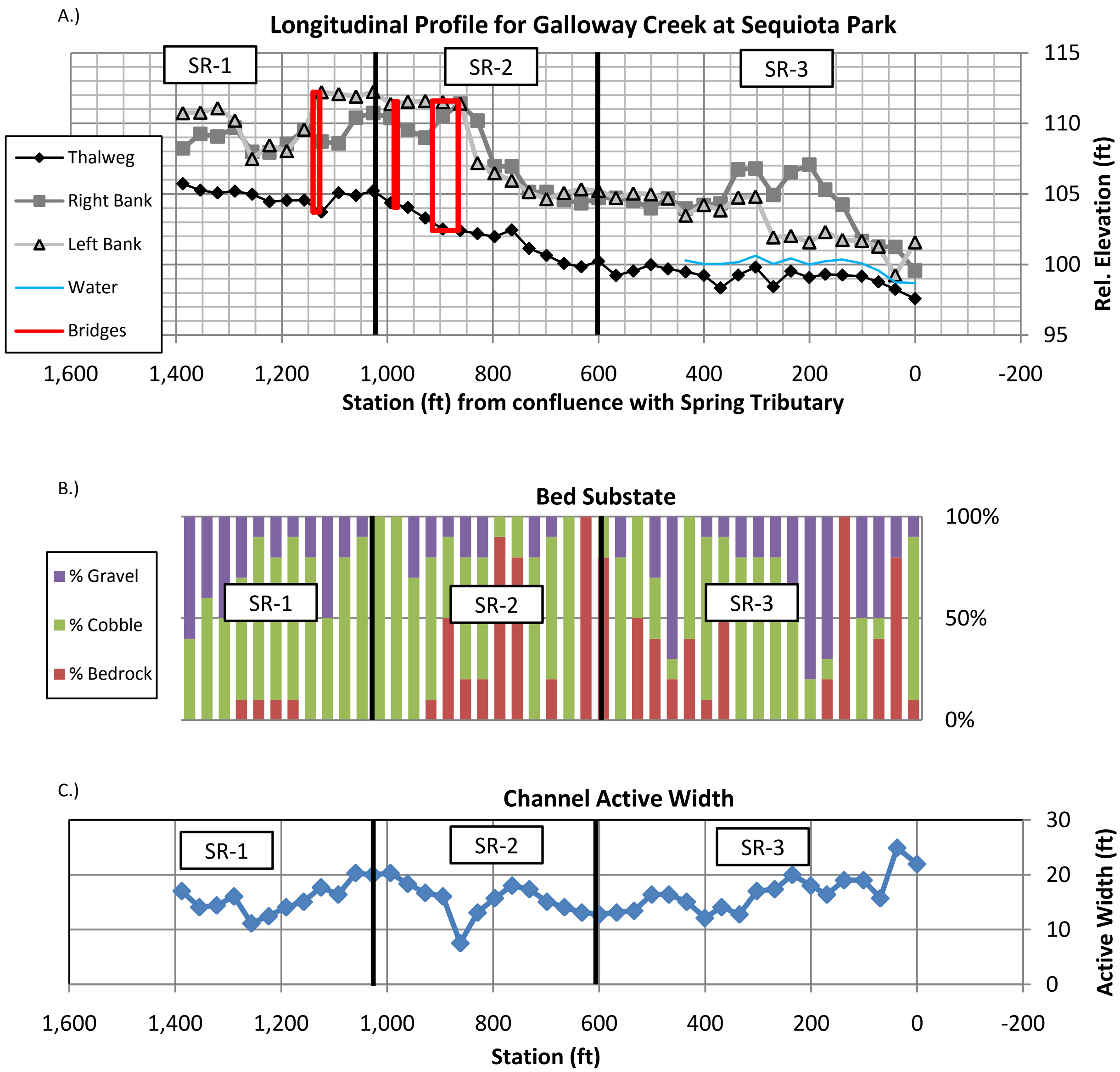

Figure 5. Project Reach Data A.) Longitudinal Profile B.) Bed Substrate C.) Active Channel Width

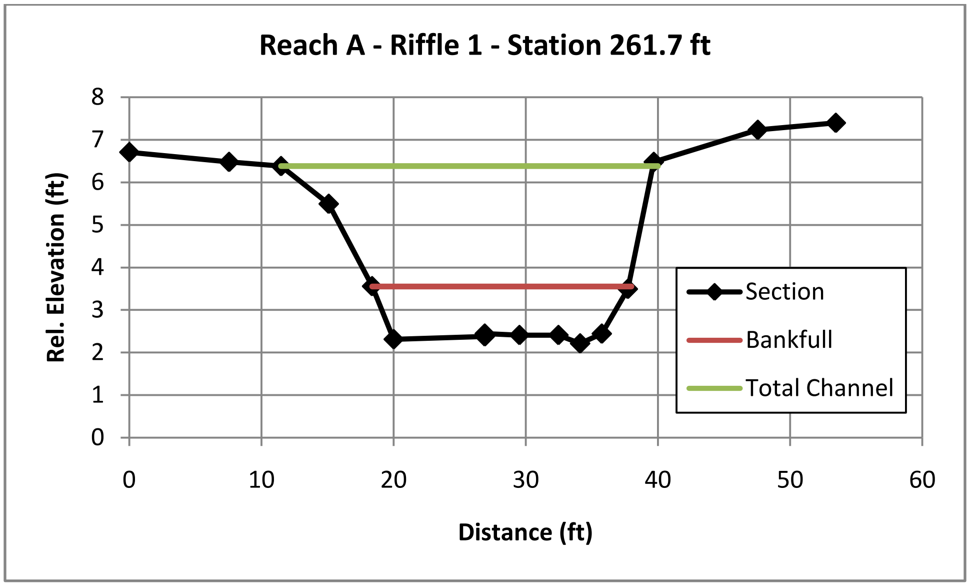

Figure 6. Reach A Riffle 1

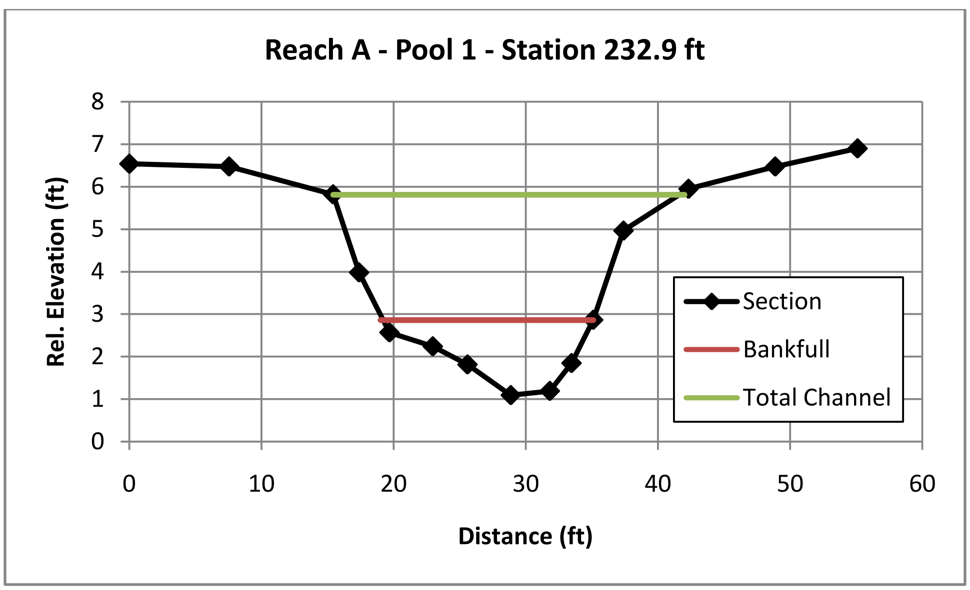

Figure 7. Reach A Pool 1

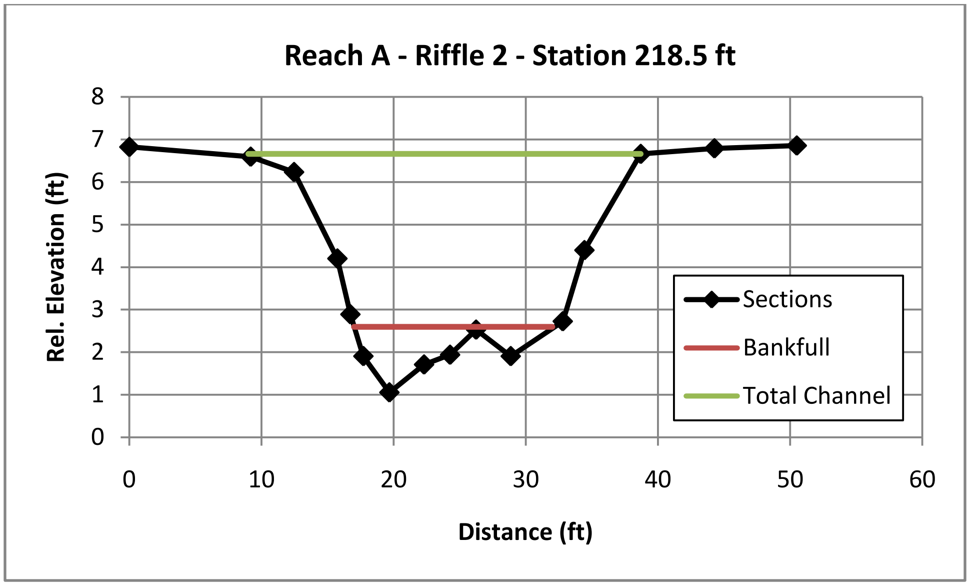

Figure 8. Reach A Riffle 2

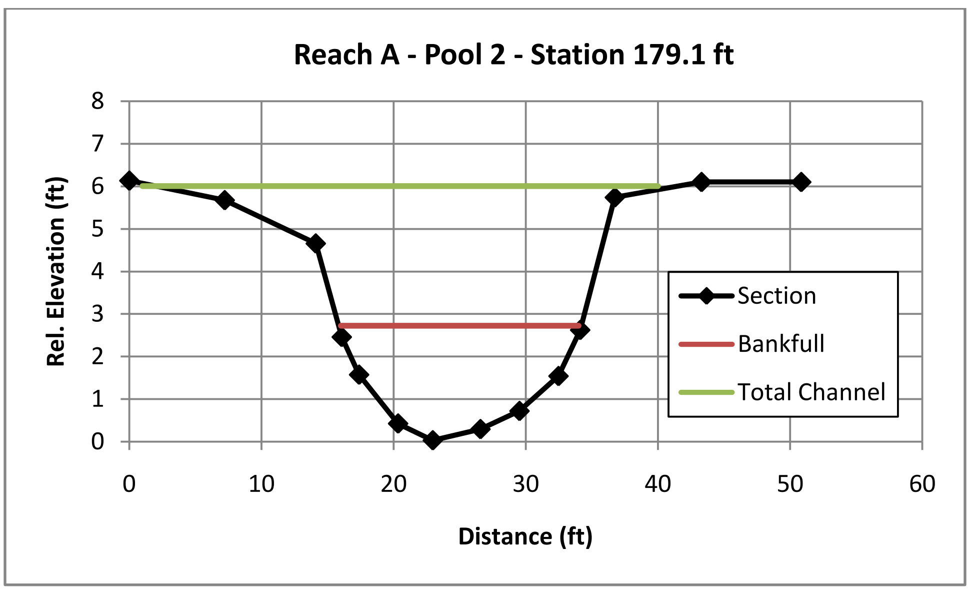

Figure 9. Reach A Pool 2

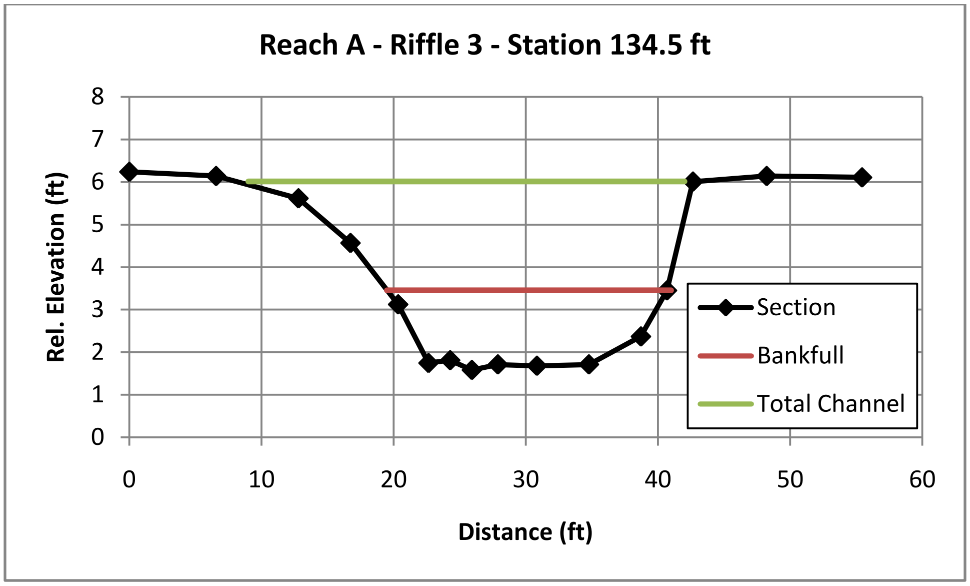

Figure 10. Reach A Riffle 3

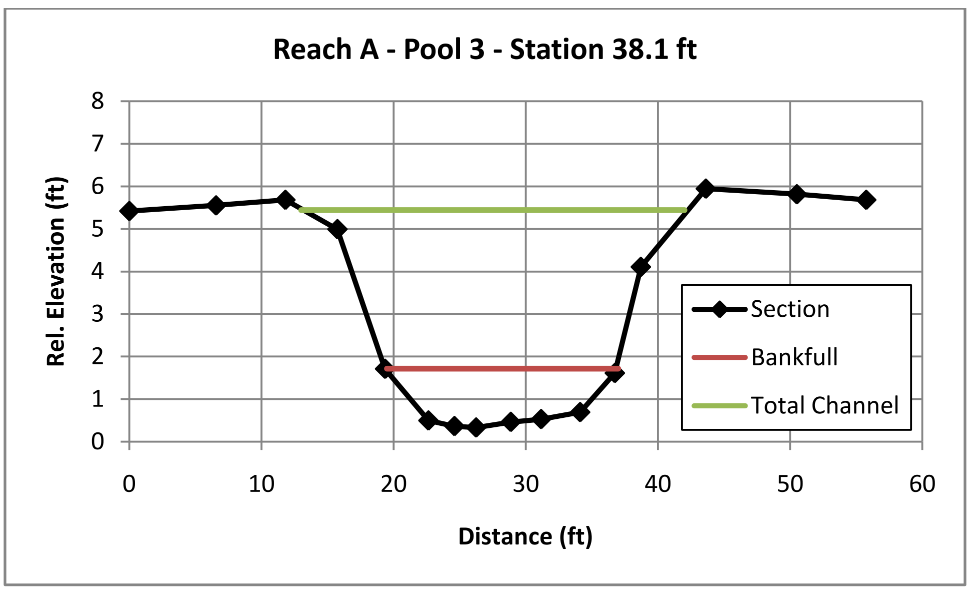

Figure 11. Reach A Pool 3

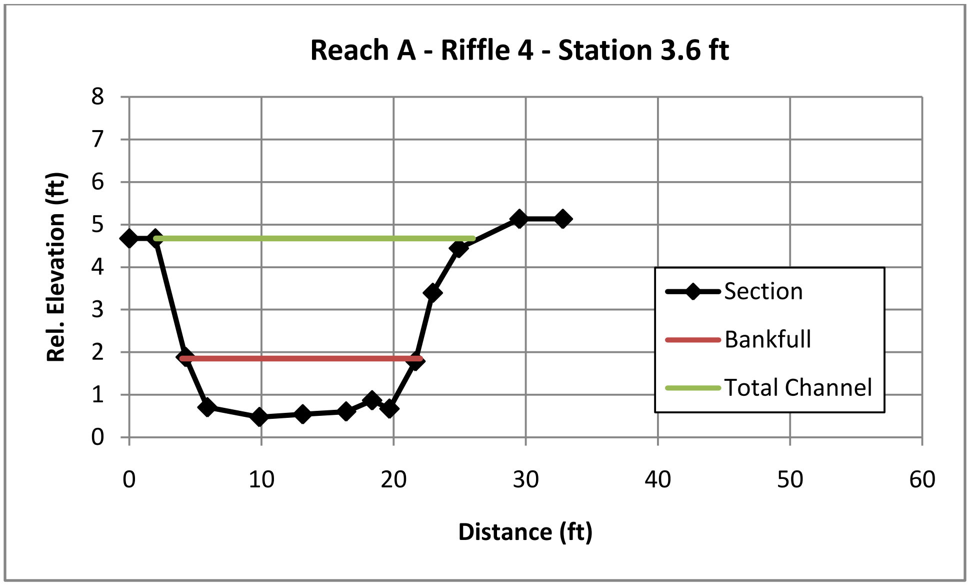

Figure 12. Reach A Riffle 4

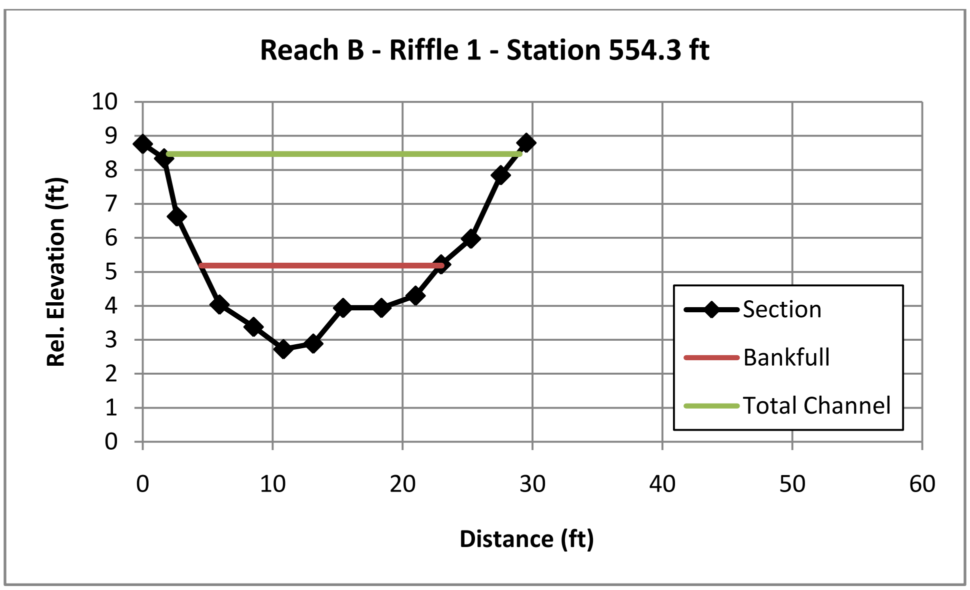

Figure 13. Reach B Riffle 1

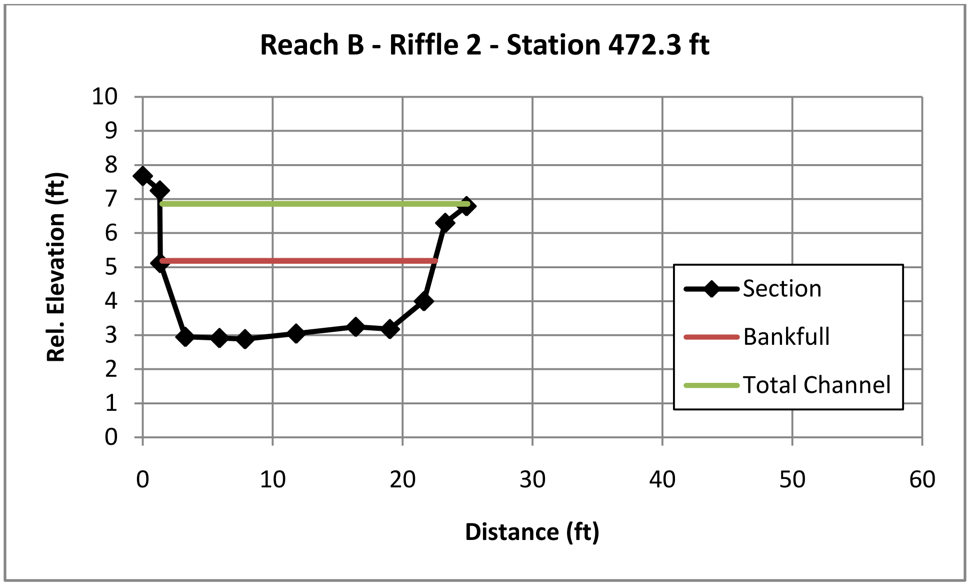

Figure 14. Reach B Riffle 2

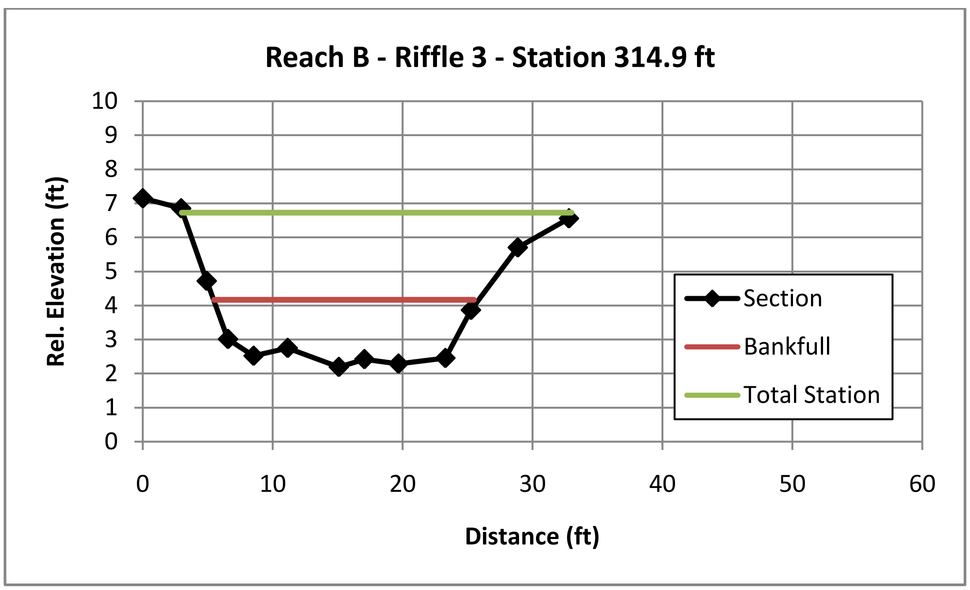

Figure 15. Reach B Riffle 3

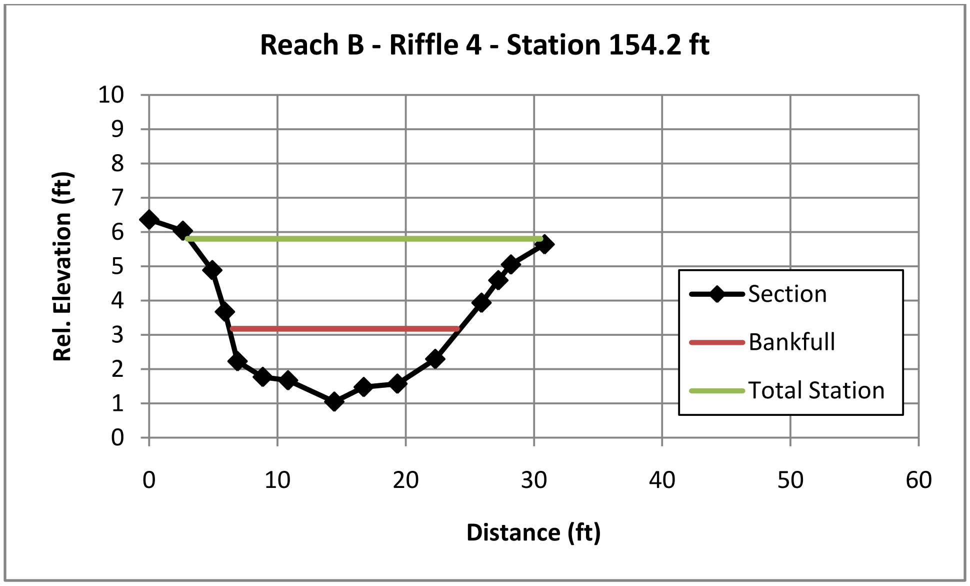

Figure 16. Reach B Riffle 4

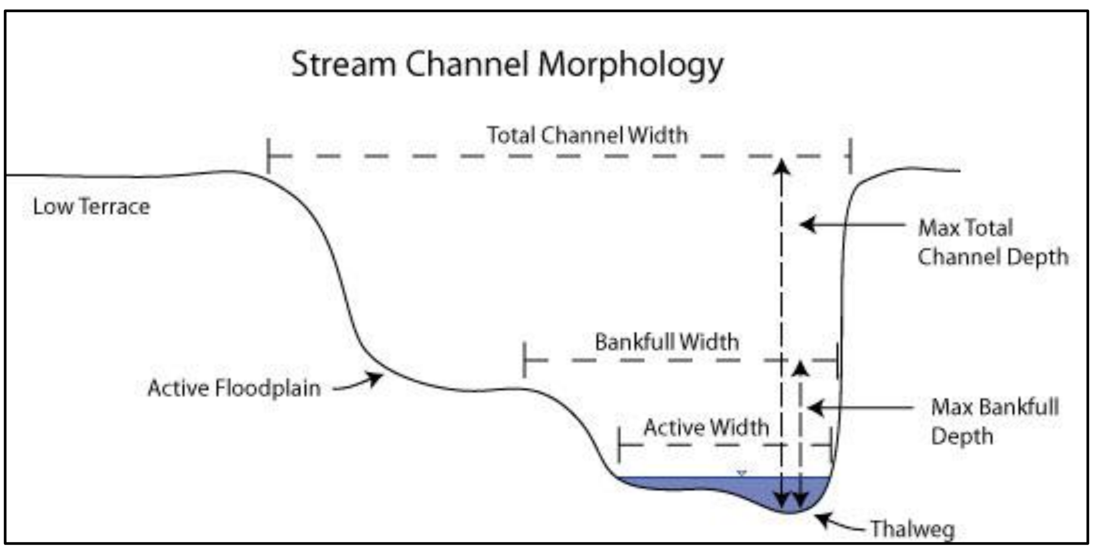

Figure 17. Typical channel morphology terminology

Photo 1. Looking downstream at SR-3 near Station 1,300 feet (10/16/2008)

Photo 2. Looking downstream at SR-3 near station 1,200 feet (10/16/2008)

Photo 3. Looking downstream at SR-3 near station 1,100 feet (10/16/2008)

Photo 4. Looking downstream at SR-3 near station 1,050 feet (10/16/2008)

Photo 5. Looking downstream at SR-2 near station 1,000 feet (10/16/2008)

Photo 6. Looking downstream at SR-2 near station 900 feet (10/16/2008)

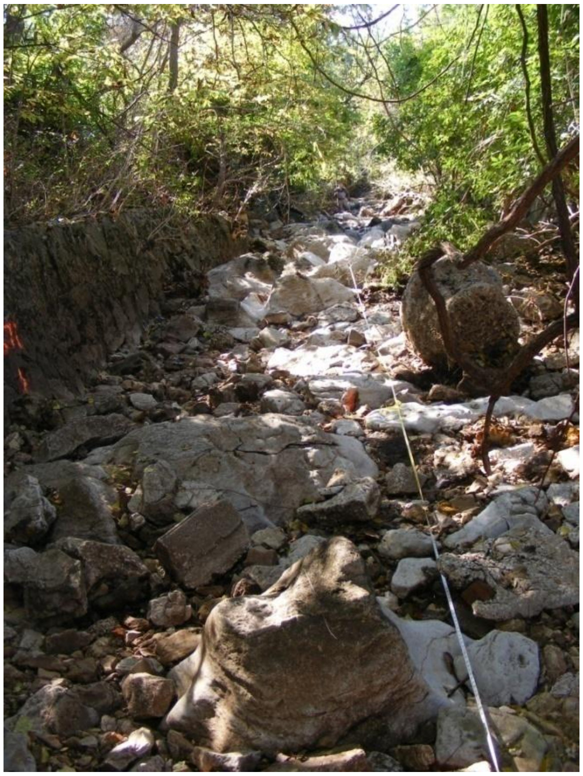

Photo 7. Looking downstream at SR-2 near Station 800 feet (10/16/2008)

Photo 8. Looking downstream at SR-2 near station 750 feet (10/16/2008)

Photo 9. Looking downstream at SR-2 near station 700 feet (10/16/2008)

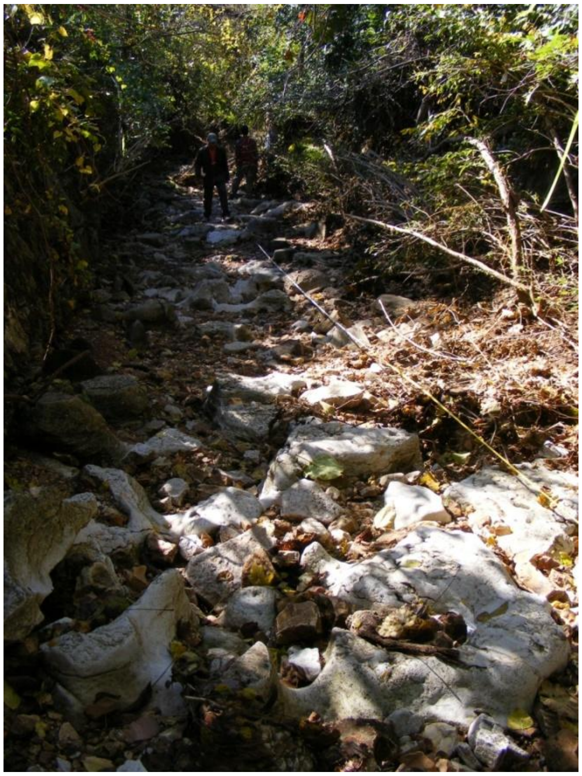

Photo 10. Looking downstream toward SR-1 near station 560 feet (10/16/2008)

Photo 11. Looking downstream at SR-1 near station 470 feet (10/16/2008)

Photo 12. Looking downstream at SR-1 near station 310 feet (10/16/2008)

Photo 13. Looking downstream at SR-1 near station 260 feet (10/16/2008)

Photo 14. Looking downstream at SR-1 near station 180 feet (10/16/2008)

Photo 15. Looking downstream at SR-1 near station 100 feet (10/16/2008)

Photo 16. Looking downstream at SR-1 near station 40 feet (10/16/2008)

Photo 17. Looking downstream at SR-3 near station 0 feet (10/16/2008)

Photo 18. Reference reach A upstream of Lacuna looking upstream (4/6/09)

Photo 19. Pool above Lacuna bridge in reference reach A looking upstream (4/6/09)

Photo 20. Bank erosion downstream of Lacuna bridge in reference reach B (4/609)

Photo 21. Bedrock bed in reference reach B looking upstream (4/6/09)

Photo 22. End of reference reach B near station 1,400 feet (4/6/09)

Photo 23. Bed material near station 1,200 feet SR-3 (4/6/09)

Photo 24. Cobble and course gravel source from backfill of failing wall along left bank near SR-3 station 1,200 feet (4/6/09)

Photo 25. Plane bed reach near station 1,140 feet looking downstream at SR-3 (4/6/09)

Photo 26. Failing concrete wall on right bank looking downstream near station 1,200 feet SR-3 (4/6/09)

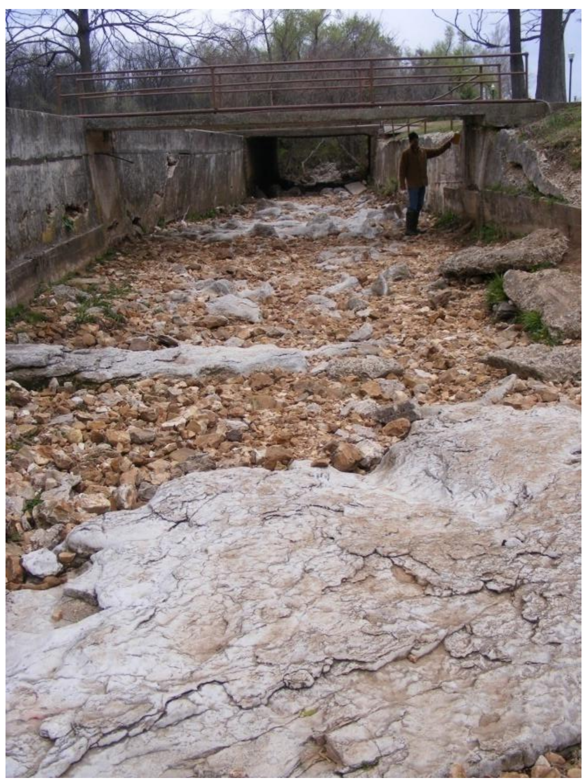

Photo 27. Bedrock bed near station 1,000 feet looking downstream SR-2 (4/6/09)

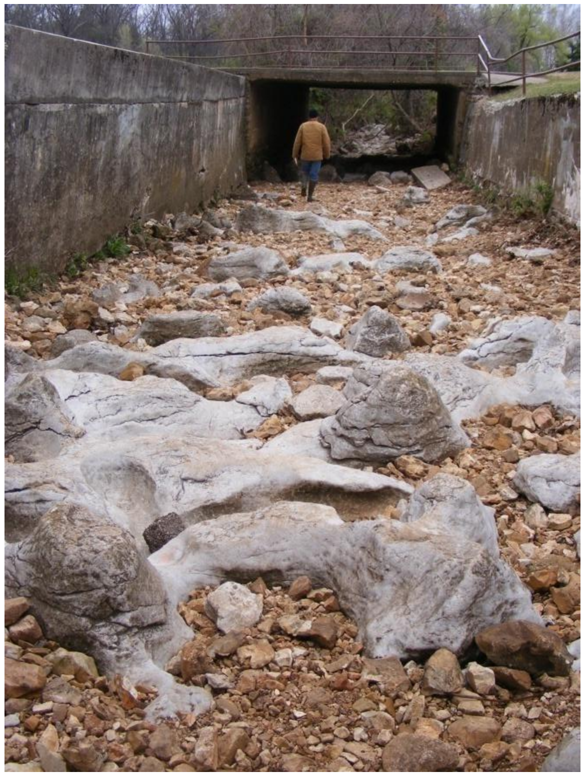

Photo 28. Bedrock pinnacles near station 900 feet looking downstream SR-2 (4/6/09)

Photo 29. High bedrock pinnacles near station 600 feet looking downstream of SR-2 to SR-1 (4/6/09)

Photo 30. Large blocks from failing walls and construction rubble at station 500 feet SR-1 (4/6/09)

Photo 31. Fine to medium gravel fill between cobble and boulder size material near station 500 feet SR-1 (4/6/09)