Ozarks Environmental and Water Resources Institute
(OEWRI)

Geomorphic Assessment of Ravenwood Creek
Lake Springfield Park, Springfield, Missouri

**Final report to Olsson Associates for
the City of Springfield, Missouri**

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Scope and Objectives

Modifications of the watershed surface and channel system during urbanization can result in downstream channel instability due to changes in storm water runoff rates and sediment load regime. This project involves the investigation of the geomorphic conditions that influence channel instability in a small stream draining a residential area of the southeastern part of the City of Springfield, Missouri. The channel has been affected by increased flooding, bed and bank erosion, and planform change. Local officials have questions about the potential risk to sewer and utility lines. In addition, local residents have concerns about the risks posed by flooding and bank erosion to their properties located downstream immediately downstream of the project site. Olsson Associates contracted the Ozarks Environmental and Water Resources Institute (OEWRI) in Spring 2007 to complete a geomorphic assessment of the 700 ft long reach of Ravenwood Creek that flows through Lake Springfield Park. The objectives of the study are: (i) perform a field investigation of the longitudinal profile, channel cross-section, substrate properties, and bank conditions present; (ii) evaluate the geomorphic setting and causes of instability; and (iii) submit a final report on stream stability and related channel restoration recommendation. This report will provide information for the planning and design process for proposed Ravenwood Creek drainage and channel improvements by the City of Springfield.

Project Location

The project area is located in the southeastern part of the City of Springfield, Greene County, Missouri in the **NW ¼ of S20-T28-R21.** At the project site, the 2nd order stream presently averages about 12 feet in active width and drains about 0.61 mi^2 of a high to moderate density residential suburban neighborhood (Figure 1). The upper portion of the drainage system within Ravenwood Subdivision has been modified during the development process to improve storm water drainage (Picture 1). The stream channel in the subdivision was channelized and straightened to convey storm water runoff from roads and lots. A concrete cover for a phone line is located where the stream flows south from the urban area and crosses the park boundary (Picture 2). While not intended to do so, the concrete cover is acting a temporary check on bed erosion and head cut migration upstream. Below this structure, almost 6 ft of incision has occurred and the channel bed gradually returns to original grade at a point about 500 ft downstream (Pictures 3 to 7). GPS points that locate the project reach and manhole benchmarks are included in Table 1.

Geology and Soils

Horizontally-bedded Burlington-Keokuk Limestone underlies the project site and most of the Springfield Plateau region in general. Karst features are common in the vicinity and include (i) collapse and solution sinkholes, (ii) expression of fracture patterns at the surface, (iii) extensive cave networks, and (iv) widely-distributed springs. The regional water table is deep, but perched water tables can occur in association with shallow bedrock, soil fragipans, and weathered clay

layers with low porosity. The flow in the channel is ephemeral and flashy due to the influence of upstream urban impervious cover, subsurface karst drainage, and locally steep topography. The project site is located along the transition area between the relatively level upland plateau surface and the steeper colluvial slopes of the James River valley. Soils in the upper areas of the contributing drainage area include the Newtonia (fine-silty paleudolls) and Pembroke (fine-silty paleudalf) series which are formed on loess-capped uplands (Hughes, 1982). The lower areas of the drainage area and site-adjacent interfluves are covered by the Wilderness (loamy-skeletal fragiudalf) and Goss (clayey-skeletal paleudalf) series. The Wilderness soil forms in weathered mixed loess and clay residuum colluvium of variable thickness and the Goss series occurs as thinner soils near occasional bedrock exposures on steeper valley slopes (Hughes, 1982).

The valley floor within which the stream is incised contains soils mapped as the Secesh (fine-loamy ultic hapludalf) and Cedargap (loamy-skeletal cumulic hapludoll) series. The Secesh series occurs on older alluvial or colluvial "low terraces" along smaller streams (Hughes, 1982). The Cedargap series represents younger (sometimes historical age) alluvium and occurs on "floodplains." About 1 to 3 ft of historical silt and clay deposition has occurred over much of the valley floor of the site as indicated by stratigraphic analysis and buried artifacts in cut bank exposures along the reach. The origin of this material is probably due to anthropogenic soil erosion and floodplain sedimentation associated with: (i) early agricultural settlement (mid to late 1800s); (ii) row-cropping boom (1930-1950); and (iii) recent urban construction phase (1970-1990). A sewer line was laid down the valley after 1975 about 50 ft to the south of the present channel location.

Methods

Pavlowsky and staff visited the Ravenwood Creek site to collect field data on three different days in 2007 (March 30th, July 9th, and November 14th) and one day in 2008 (April 29th). A Topcon total station was used to complete longitudinal profile and cross-section surveys. A Trimble GeoXH GPS receiver was used to collect geospatial points for GIS analysis. Longitudinal profiles were determined for three geomorphic surfaces: (i) thalweg or channel bottom, (ii) bankfull stage, and (iii) tops of both low terrace banks. Bankfull stage was identified using the following field indicators: (i) maximum height of bed load transport or flat gravel bar tops, and (ii) break in bank slope where a lower vertical eroded bank changed to a more stable or vegetated upper bank. Caution must be used when evaluating the bankfull channel dimensions described in this report since the channel is heavily disturbed and channel conditions can vary greatly over time and downstream distance.

Bed material diameter in millimeters was evaluated by using a ruler to measure the B or intermediate axis of 20 different pebbles collected along a "zig-zag" transect within seven 30 to 50 ft long patches of the active bed. In addition, measurements of the 5 largest pebbles within each channel patch area were also recorded. Channel morphology and hydraulic data were analyzed with Hydroflow Express software by inteliSOLVE and used to calculate bankfull velocity, discharge, and shear stress (Rosgen, 2006). Bankfull shear stress values (Tc) were used to determine the critical bed material diameter using the empirical equations of Leopold et al. (1964) as $Dc(mm) = 77.966Tc(lbs/ft^2)^{1.042}$ and Rosgen (2006) as $Dc = 152.02\ Tc^{0.7355}$.

Watershed and Channel Condition

The 1839 General Land Office Survey indicates that the drainage basin of the study site was in "timber" but the stream itself was not identified. At that time, farmsteads were located on the valley floor of the James River in the vicinity of the project site, but not at the site or within its drainage area. Historical aerial photography of the project site and its drainage basin was reviewed for the years 1936, 1953, 1975, and 2005. In 1936, the entire basin area was in row-crop and heavy pasture agriculture with <5% under forest. The channel bed and bank lines were evident and showed that the main channel was further to the south than at present. A cattle trail or chute channel was visible on the inside of the bend near the position of the present channel. In 1953, a few more roads and residences were in the area but the basin still was mainly agricultural and in pasture. In the 1953 photograph examined, the stream course in the project reach was less defined and looked more like a grassed waterway than a stream channel. Channel filling after 1936 is supported by field evidence at the site where old horse-drawn wagon parts (wheel and bed boards) are found partly exposed buried by almost 3 ft of alluvium.

By 1975, the upper half of the basin was covered in low to moderate density single-family houses with the drainage area now about 50% developed, 30% recovering forest, and 20% grazing pasture. A single channel was obvious in the photograph. In 2005, the basin was >90% urbanized and since 1975 a municipal sewer line had been run down the valley of Ravenwood Creek through the project site. The channel was well defined with sharp bank lines, but its course was now more than 100 ft to the north of where it was in 1975 (Figure 2). This "straightening" of the channel was probably caused by either the incision of a chute cutoff channel or the consequence of disturbance or relocation during sewer line construction.

Channel Morphology

The profile of the channel thalweg shows that slope varies downstream according to the degree of channel incision and substrate condition from 0.002 to 0.013 ft/ft (Figure 3). The upstream grassed channel has a slope of 0.009 taken from the tops of the concrete utility covers that cross the channel bed. The channel cross-section also varies within the project channel south of the park boundary from 9 ft to 18 ft in bankfull width, 20 ft to 30 ft in top bank width, and 6ft^2 to 11 ft^2 in bankfull area (Table 2, Figure 4). The grassed channel has an average bankfull width of 10 ft and area of 5 ft^2. A classical model of knick point migration and head cut form can be used to interpret the dominant geomorphic processes controlling the form and instability of this reach (Schumm et al. 1987) (Figure 5). Based on this model and other field observations, a sub-reach classification of the project channel follows below.

Sub-reach #1 occurs between stations 878 ft to 667 ft and directly drains the residential community in a grass-lined channel (Figure 4a and Picture 1). The upper bank angle along this reach is relatively low ranging from 30 to 40 degrees and top bank width averages about 18 ft. The top bank surface is 3 to 5 ft above the channel bed or about 3x the bankfull stage. Channel slope ranges from 0.0068 along the channel bed to 0.0106 between the crests of the two concrete utility covers. The bed is stable and has been scoured or graded to bedrock in several places. Typical bankfull channel dimensions are 10 ft in width, 0.6 feet in mean depth, and 6ft^2 in area (Table 2). This reach is analogous to the zone of the "oversteepened reach" below the "precursor knickpoint" (Figure 5). However, erosional affects are attenuated by the protection of the two concrete utility covers in this reach. In Spring 2008 after several >20 year storms had hit the

Springfield area in less than three months, the presence of new bed forms and bar materials indicated that some bed load sediment was being transported from the residential area downstream to the project site.

Sub-reach #2 extends downstream from stations 667 ft to 530 ft and represents a recently active portion of a headward incising channel or "headcut." However, upstream migration of the head cut has presently stalled due to inadvertent bed protection by the concrete cover (Figure 5 and Picture 2; note exposed PVC pipe under apron to the left side of the picture). This is a zone of local channel disequilibrium where the bed form is flat or uneven and bed slope approaches zero. There are three zones in sub-reach #2. <u>Sub-reach #2A</u> designates the zone of maximum incision depth immediately below the concrete cover forming a large "plunge pool" between stations 667 ft and 640 ft. Channel bed elevation drops by almost 6 feet over a horizontal distance of a few feet to expose bedrock between 660 ft to 655 ft. Upper bank angles range from 60 to 90 degrees and top bank width is 27 ft across the plunge pool. Top bank height is 9 ft above the bed. Bankfull stage indicators were not identified in this sub-reach. The underground pipe and phone line was almost completed undermined in April 2008 and should be checked by authorities as soon as possible.

<u>Sub-reach #2B</u> is a zone of scour and sediment transport extending below the core zone of the plunge pool from 640 ft to 575 (Pictures 3 and 4). Bedrock is exposed in some places between patches of gravel sheet deposits. Upper bank angle averages about 60 to 80 degrees and top bank channel width is 25 ft. Top bank heights rise from 5 to 7 ft above the bed, about 5x bankfull stage. <u>Sub-reach #2C</u> is a zone of deposition between stations 575 ft and 530 ft where the erosional energy of the plunge pool has dissipated (Picture #5). The rate of bed load delivery into the project reach from upstream sources is probably relatively low compared to the amount of gravel and cobble released by bed and bank erosion in the plunge pool zone or from channel widening in sub-reaches 2A and 2B. Channel width and depth trends are similar to sub-reach #2B. There are two locations where historical farm artifacts are buried by about 3 ft of alluvial and presently exposed in eroding banks on the right side of the channel. A wagon bed and frame (not really sure, but my best guess) is located at 615 ft and the iron band from around an old wagon wheel is found at 565 ft. These artifacts are presently (April 2008) being unearthed by lateral bank erosion with several pieces already on the channel bed available for transport.

Sub-reach #3 extends from 530 ft to 369 feet (Pictures 6 to 8). Channel slope in this reach averages about 0.0063. This is a reach where there is a relatively long bend to the left or north by the channel and a long lateral pool trough has formed along the cut bank as expected between stations 520 ft to 410 ft. There are also several smaller-scale erosional steps at stations 500 ft to 470 ft within the longer pool form (Figure 3). Thus, this reach may reflect the composite influence of both meander pool and secondary knickpoint formation (Figure 5). The top bank width of the channel reaches 30+ ft and bankfull width ranges from 13 ft to 18 ft (Figure 4b). Top bank height ranges from 4 to 7 ft, about 3 to 5 times the bankfull stage. Five riffles, including smaller steps, occur in this sub-reach with an average riffle crest spacing of 40 ft. A poorly developed point bar and incipient floodplain has formed on the inside of the bend with exposed and almost vertical upper banks occurring on the outside bend.

Sub-reach #4 occurs between stations 369 ft and 19 ft and generally represents the "aggradational zone" at the tail end of both the head cut and long eroding cut bank (Figure 5; Pictures 9 to 13). This sub-reach presently shows signs of incision in several places into the aggraded gravel on the channel bed and scour to underlying cohesive material. The recent trend of incision in the sub-reach is possibly related to the decrease in sediment supply from upstream sources and relative increase in sediment export (i.e. negative sediment budget). As the sediment load released from eroding bed and banks decreases, the excess fluvial energy is applied to the bed causing erosion. As also observed in April 2008, woody debris from yard waste dumping, ice storm tree damage, and bank erosion litters the secondary channel area and channel "flood plains" along most of the reach, possibly obstructing flow and also increasing bed erosion.

Sub-reach #4A extends from 369 ft to 92 ft. Here the channel is relatively wide with low banks (Figure 4c). Top bank width is 25 ft and bankfull width is 8 ft. The top bank height is only 2 to 3 ft or 2+ times the bankfull height. The planform of the channel changes to a split or double thalwag habit in this reach. One channel thread tends to be the primary thalweg (on the right side) while the other appears to be a secondary chute channel (left side). Deposition of sediment into a mid-channel bar form or bench occurs between these channels. Sub-reach #4B occurs from 92 ft to 19 ft. The channel is still double-threaded but the primary channel thread switches from the right to left side of the channel. The channel narrows in this sub-reach to a top channel width of 21 ft and a bankfull width of 4 ft (Figure 4b). Top bank height is about 3 to 4 ft from the bed of channel or about 3x the bankfull stage. The bed elevation and slope of sub-reach #4B may reflect that of the pre-incision channel and bed slope increases to 0.0125 slightly below station 144 ft. Eight riffles were identified between stations 369 ft and 40ft for an average riffle crest spacing of 41 ft.

Sub-reach #5 occurs between stations 19 ft and zero ft. The form of this reach is largely controlled by the large concrete apron at station zero where the stream flows off park property (Picture 14).

Sub-reach #6 occurs from zero to -140 ft (notice negative sign indicating that this sub-reach is downstream of station zero) (Picture 15). This reach is not on park property but was visually evaluated for geomorphic stability. Upper banks are steep and top bank heights are about 4 to 5 ft off the bed, or about 2 to 3x bankfull stage height. Top bank width is 17 ft and active bank width is about 4 ft. Fill from residences infringe on the channel area on both sides in some places. A 12" white PVC line is exposed on the channel bed at station -108 ft. On April 29, 2008, construction of a new channel with stone bed and banks was in progress at the end of sub-reach #6.

Bed and Bank Materials

Pebble counts of the active bed were completed for seven patches in the channel (Table 3). The D50 and D84 of the project reach are typically in the median to coarse gravel range of 8 to 32 mm. The coarsest mobile material in the channel is large cobble from 180 to 256 mm. As expected, the bed substrate becomes finer where sediment delivery to the bed increases such as in the case of bank erosion in sub-reach #3 and head cut-related aggradation in sub-reach #4. In these areas, the median particle size on the bed is in the fine gravel range from 2 to 8 mm. The

bed is potentially mobile at the bankfull discharge determined for the reach by this study. Critical diameters of bed mobility range from medium to very coarse gravel (Table 4).

Bank soil materials are primarily composed of silty alluvium and cherty silty clay or loamy colluvium. Chert gravel is commonly found in the middle to lower portions of cutbanks, but not in all places. In addition, cherty limestone residuum of silty clay texture may outcrop at the base of the banks near the bed, often in association with exposed (or nearly so) bedrock. Wilderness-Goss soils formed in colluvium typically have liquid limits ranging from 20 to 40 percent and plasticity index values ranging from 2 to 20 percent (Hughes, 1982). Secesh-Cedargap soil series formed in alluvium typically have liquid limits ranging from 20 to 40 percent and plasticity index values ranging from 3 to 25 percent (Hughes, 1982). Stable upper bank angles for these materials range from 30 to 40 degrees based on field observations.

Nature and Cause of Channel Instability

The main forms of channel instability in the project reach are channel incision (sub-reaches #2, #3 and recently #4), bank erosion caused by channel widening (sub-reaches #2 and #4), and lateral channel migration and aggradation (sub-reach #3). A generalized model of a "stalled" head cut with a well developed plunge pool is used here to describe the geomorphic setting of the reach (Schumm et al. 1987) (Figure 5). Bedrock is exposed in the bed and along lower banks where incision has been severe. Material released to the channel by bed and bank erosion is being transported downstream to some extent, but much is also being stored in a point bar deposit in sub-reach #3 and channel aggradation zone in sub-reach #4. Either the reduction of sediment supply due to the stalled head cut and/or flow obstruction by woody debris has caused incision in some previously aggrading areas in sub-reach #4 as observed in April 2008.

The major causes of geomorphic instability in this reach are linked to: (i) preconditioning by historical agricultural land disturbance and related colluvial/alluvial deposition in the reach; (ii) increased storm water runoff by construction of impervious area and storm sewer improvements; and (iii) relocation and straightening of the channel during sewer line excavation activities and/or catastrophic incision of a secondary chute channel in response to flooding. This shift in the channel to a position about 100 ft further north between 1975 and 2005 effectively reduced channel length in the project reach by about 150 feet and thus increased channel slope by 20 percent. The channel is now slowly adjusting to its previous form in two ways: (1) lateral migration to the south toward the old location; and (2) knickpoint formation and head cutting to reduce slope to balance sediment transport and supply.

Several other secondary, but significant, factors also contributed to channel instability within the project reach. First, the site is located in a valley containing relatively thick colluvial deposits that allowed the channel the freedom to incise deeper than expected. In some places it cut down over six feet below the pre-existing bed. Bedrock is usually near the base of the thalweg along many Ozark streams and thus potential incision depths are generally limited. Second, stratigraphic evidence in cutbank exposures of the old channel course indicate that several cut and fill cycles formed a coarse cobble lag under the channel. This lag protected the erodible colluvium below it from bed scour and channel incision. The coarse lag protection along the channel bottom was absent in the location of the straightened channel and thus incision was further enhanced. In April 2008, imbricated angular limestone cobbles were found exposed at

the base of the right bank at around the 600 ft point at the same elevation of the present degraded bed. These paleo-channel bed lag deposits suggest that significant channel incision occurred at this location prior to 1800 due to climate change or natural sediment supply variations. This is more evidence of the fact that this location is prone to periodic incision and cut-and-fill cycles.

Finally, there is excess energy for sediment transport in the stream and "hungry water" increases bed and bank erosion in order to maintain the "equilibrium" balance between sediment transport and channel form. Observations of the channel bed along the upstream grass-lined channel (sub-reach #1) indicated that active bed load transport did occur during the period of several large floods in winter and spring 2008. However, it is highly probably that sediment delivery to the project channel from the upstream basin area is now reduced relative to historical conditions associated with peak land disturbance due to agriculture and more recent urbanization. After the construction phase was completed, most bare soil areas were healed-over with grass or landscaping and therefore decreased the loads of gravelly and fine-grained sediments to the project reach. The grassed reach is relatively stable and has only exhibited minor bed instability after several severe floods in 2008. It is expected that the recent bed scour areas formed in the grass channel will recover in the future.

Recommendations

Any attempt to stabilize the channel needs to consider the planform and geomorphic conditions present prior to channel straightening. The historical channel slope was probably in the range of 0.007 to 0.01 ft/ft. The slope of the channel between stations 667 to 144 ft where the bed elevations have been affected by head cutting and aggradation is about 0.0063, slightly lower than the historical slope. The slope of the post-1975 "straightened" channel prior to the initiation of incision and head cutting was higher at about 0.0118.

The project channel is slightly wider and deeper than the grassed channel and has a bankfull area that is about 30% larger. Average bankfull channel dimensions of the project channel are: 14 ft wide, 0.57 ft mean depth, 1.2 ft maximum depth, and 7.3 ft^2 in area (Table 2). Top bank heights above the channel bed in the areas not affected by head cut incision are about 3 to 4 times the bankfull stage height. Top bank widths are presently 25 to 30 feet. The width:depth ratio for sub-reach #2 is 15, sub-reach #3 is 16 to 33, and in sub-reach #4 values range from 9 to 59. For the upstream grass channel, the average bankfull dimensions are: width, 10.2 ft; mean depth, 0.52 ft; maximum depth, 0.81 ft; and area, 5.1 ft^2.

These channel dimensions compare reasonably well with those predicted from drainage area-morphology equations derived from a data set of over 32 reaches measured in the South Dry Sac Creek watershed located 10 miles to the north of the project reach. Using a drainage area of 0.61mi^2, these "regional regression curves" predict a bankfull channel with a width of 12.7 ft, mean depth of 0.69 ft, area of 8.8ft^2, and width:depth ratio of 18 (Pavlowsky, 2004). These dimensions indicate that the predicted channel dimensions are slightly larger than those measured in both the project and grassed channels. The channel area of the present project reach is about 17% less than predicted and the grass channel area is about 38% less. These differences may be explained by variations in local site factors, error in the equation, and lack of sufficient time and sediment deposition to develop floodplains and deposit higher low banks. Extending bankfull depth upward to make up the difference in channel area would yield a rectangular

design channel of about 14 ft wide and 0.7 ft deep. For the grass channel, the rectangular channel would be 10 ft wide and 0.9 ft deep.

The riffle crest spacing for an alluvial channel is typically 5 to 7 times the bankfull width. The project channel has an average riffle crest spacing of 41 feet ranging from 20 to 65 ft. With the observed bankfull width of 14 ft, the expected spacing would be > 70 feet, so the observed spacing is shorter than expected. In these relatively wide and shallow channels (w/d > 20), active bed width across the zone of active bed transport on the bottom of the channel may be a better predictor of riffle crest spacing. Active width is typically about 0.6 times the bankfull width and this would scale the riffle crest spacing to 5.1 active bed widths in length. There is one lateral "cut bank" trough pool along the right or south side of the channel in sub-reach #3. Most of the other pools in the project reach are composed of scour and fill steps or bounded by poorly developed gravel riffles. Maximum residual pool depths in the project reach typically range from 0.5 ft to 1 ft. This is the depth from the bottom elevation of the deepest pool point to the top of the downstream riffle crest.

Channel bed and lower bank protection will probably be needed to stabilize this reach. To be safe, the bed and low banks of the channel will need to be minimally protected by rock in the small boulder size (256 to 512 mm) to prevent channel incision into the erodible colluvium over which it flows. If the channel planform cannot be shifted back to the south, then well-designed drop structures will be needed to make up the slope difference and dissipate excess energy. Upper banks, above the bankfull stage should be stable at slopes ranging from 30 to 40 degrees.

The present channel is capable of mobilizing the sediment size distribution determined by pebble counting on the active bed. The dominant substrate size is probably in the range of fine to coarse gravel (4 to 32 mm) with the largest mobile clasts in the large cobble size class (128 to 256 mm). However, most of the sediment in transport on the bed has probably been supplied locally from bed and bank erosion sources. Thus, any plans to restore this channel must take into account that little sediment is being supplied to the reach from upstream watershed sources. This statement assumes minimal influence of episodic sediment delivery events associated with intense storms, construction activities, or failing storm water systems upstream. Thus, the deposition of excess fine-grained and gravel sediments to supply the long-term recovery of the channel and floodplain by "natural" channel restoration may be limited. Recent evidence indicating that the previously aggradational sub-reach #4 is now beginning to incise suggests that the channel may be recovering from the excess gravel load supplied by release from the bed and banks during active incision and head cut migration in the recent past.

Update

In order to verify the findings of this report, the Ravenwood site was visited on April 29, 2008. Over the previous three months, three large storms had hit the area and we wanted to check the condition of the project channel after these intense events. In general, the channel did not change much and the conclusions of the report were verified. However, the aggradational reach (SR #5) showed evidence of incision and several pool areas has deepened. These channel effects are consistent with the expected influence of the catastrophic forces generated by three large floods over a relatively short period of two months. However, bed erosion in the "aggradational" reach may indicate a switch has been crossed from deposition of excess bed load to bed erosion due to

a negative sediment budget. The head cut has stalled at location of the concrete phone line cover and the amount of sediment being introduced to the stream from plunge pool erosion and channel widening may have decreased significantly.

A photograph log of the Ravenwood Tributary on April 29, 2008 is included at the end of this report beginning with Picture 16. This series of photographs documents the present form and condition of the channel.

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Tables and Figures

Table 1: GPS Point Locations

UTM X	UTM Y	Point Description
477010.313415	4108167.271530	Upstream Limit of Survey 878 ft.
477017.129367	4108106.877190	Property Line at Headcut/Drop Structure 667 ft.
477169.425102	4108101.397990	Downstream Limit of Survey 0 ft.
477198.933652	4108132.743210	Downstream Limit of Investigation at Grade Control Structure -140ft
477179.194459	4108097.117530	Manhole Cover Benchmark 1
477038.198037	4108054.571960	Manhole Cover Benchmark 2
477006.739900	4108105.522900	Manhole Cover Benchmark 3

Table 2: Channel Cross-section Data.

Sec ID	Width	D (max)	D (mean)	R	A	Wp	Slope	Mannings	Mean V	Q
Station	feet	feet	feet	feet	$feet^2$	feet	ft/ft	"n"	ft/s	ft^3/s
844	7.97	1.11	0.77	0.71	6.121	8.58	0.0091	0.03	3.80	23.28
811	13.85	0.55	0.28	0.28	3.887	13.97	0.0091	0.03	2.02	7.87
778	10.03	0.89	0.65	0.62	6.481	10.52	0.0091	0.03	3.45	22.35
745	11.05	0.9	0.57	0.55	6.279	11.38	0.0091	0.03	3.20	20.11
713	8.42	0.82	0.50	0.48	4.221	8.76	0.0091	0.03	2.92	12.34
680	9.64	0.59	0.37	0.36	3.558	9.76	0.0091	0.03	2.43	8.63
614	12.92	1.48	0.86	0.82	11.12	13.53	0.0018	0.035	1.59	17.73
483	10.25	1.5	0.62	0.58	6.332	10.89	0.0059	0.035	2.29	14.49
417	18.02	1.05	0.55	0.52	9.915	18.9	0.0059	0.035	2.14	21.19
286	9.09	1.6	0.97	0.89	8.817	9.96	0.0063	0.035	3.13	27.64
230	18.76	0.7	0.32	0.31	5.975	19.16	0.0069	0.035	1.63	9.74
66	13.64	0.9	0.41	0.39	5.623	14.29	0.0125	0.035	2.56	14.42
Mean										
US Grass	10.16	0.81	0.52	0.50	5.09	10.50	0.0091	0.03	2.97	15.76
Project Site	13.95	1.15	0.57	0.54	7.33	14.64	0.0075	0.035	2.35	17.50

Red Letters — Modeled mean Q of St. 66 through 483 not included in mean values

gray box = concrete bottom and sides

Table 3. Bed Sediment Size Data.

Reach	Patch	Bed Pebble Count Size Distribution (n=20)					Max Mobile Clast (n=5)			
	Station (ft)	Dmin	D16%	D50%	D84%	D95%	Mean	s	Cv%	Max
1	878 to 819						217			250
1	806 to 688						200			250
2B	645 to 578	0.5	3	28	70	140	196	21	11	220
2C	578 to 528	2	2	25	80	110	170	34	20	210
3	495 to 445	0.5	0.5	3	30	45	130	69	53	250
4A	379 to 328	0.5	0.5	17	45	50	152	35	23	210
4B	145 to 95	0.5	0.5	7	25	30	126	38	31	170
5	32 to 9	2	8	13	50	60	170	67	39	250
6	-21 to -71	0.5	5	23	45	100	150	35	24	210

Table 4. Sediment Mobility at Bankfull Discharge

Sec ID Station	Shear (lbs/ft^2)	Critical Dia (mm)[1]	Critical Dia (mm)[2]	D16 mm	D50 mm	D84 mm	Dmax mm
844	0.41	Grass Channel		Grass Channel			
811	0.16						
778	0.35						
745	0.31						
713	0.27						
680	0.21						
614	0.09	7	26	3	28	70	220
483	0.21	16	49	1	3	30	250
417	0.19	14	45	1	10	38	230
286	0.35	26	70	1	12	35	190
230	0.13	10	35	1	12	35	190
66	0.31	23	64	3	10	38	210
Mean							
US Grass	0.28						
Project Site	0.24	18	53	1	9	35	214

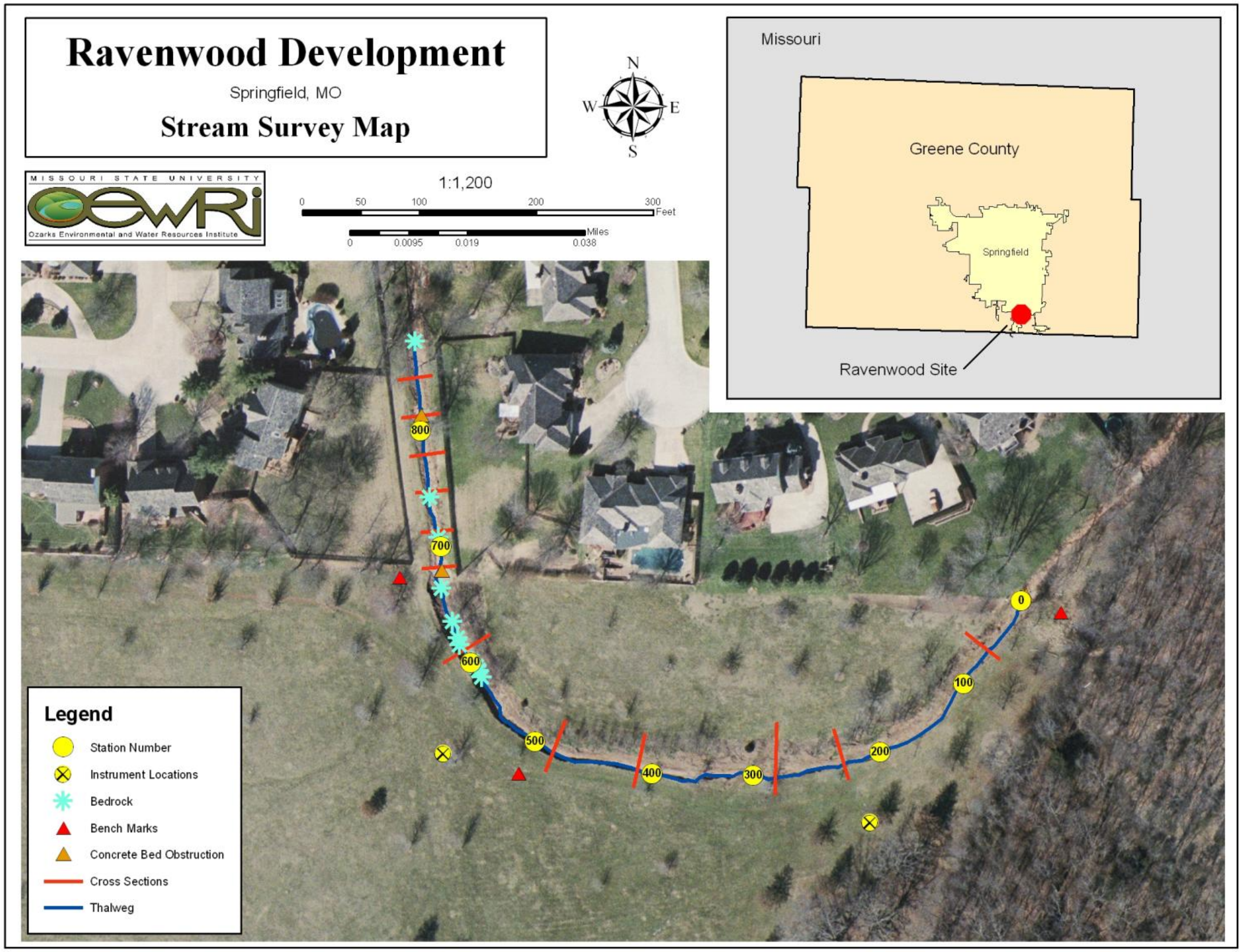


Figure 1: Stream Survey Map

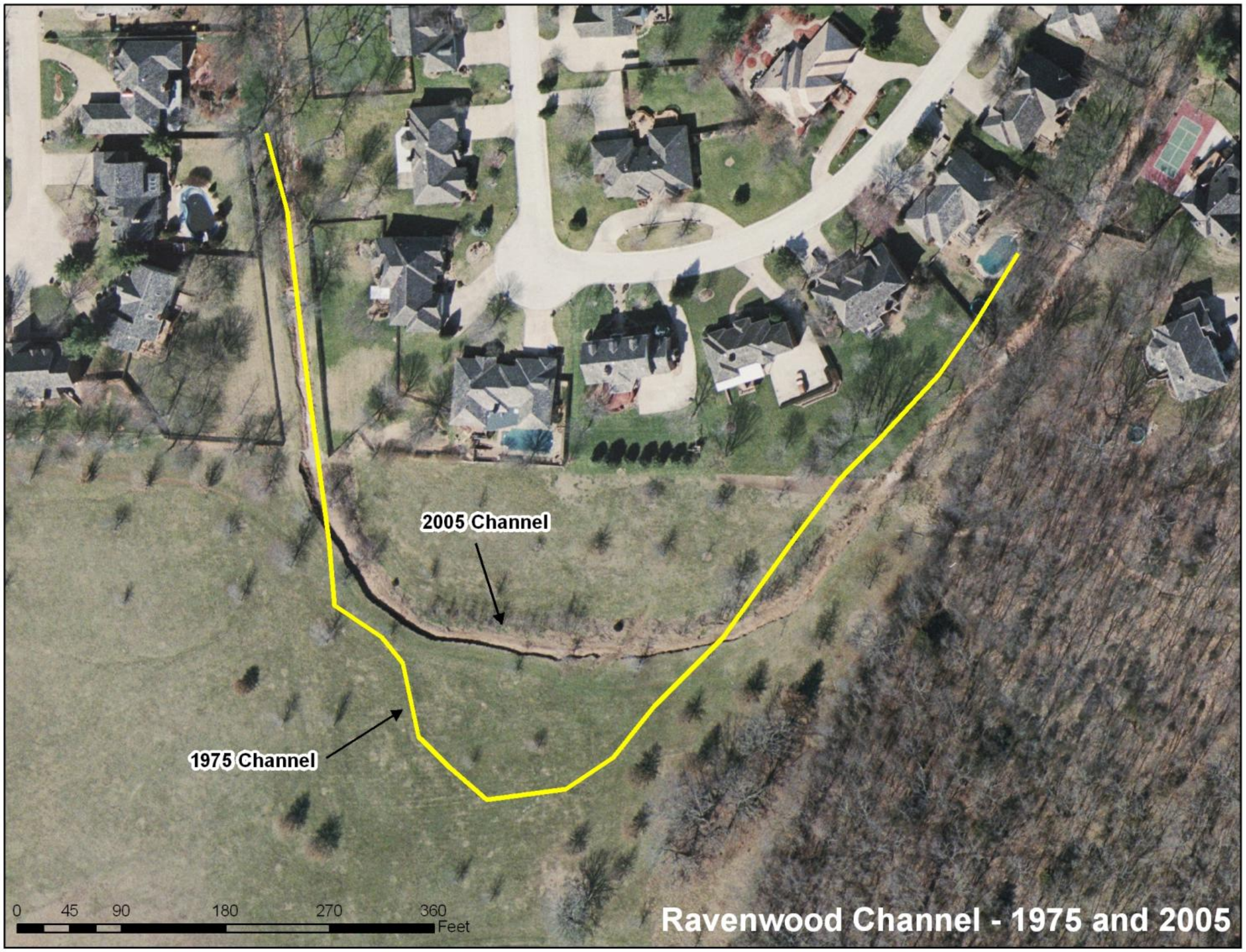


Figure 2: Comparison of 1975 and 2005 channel position

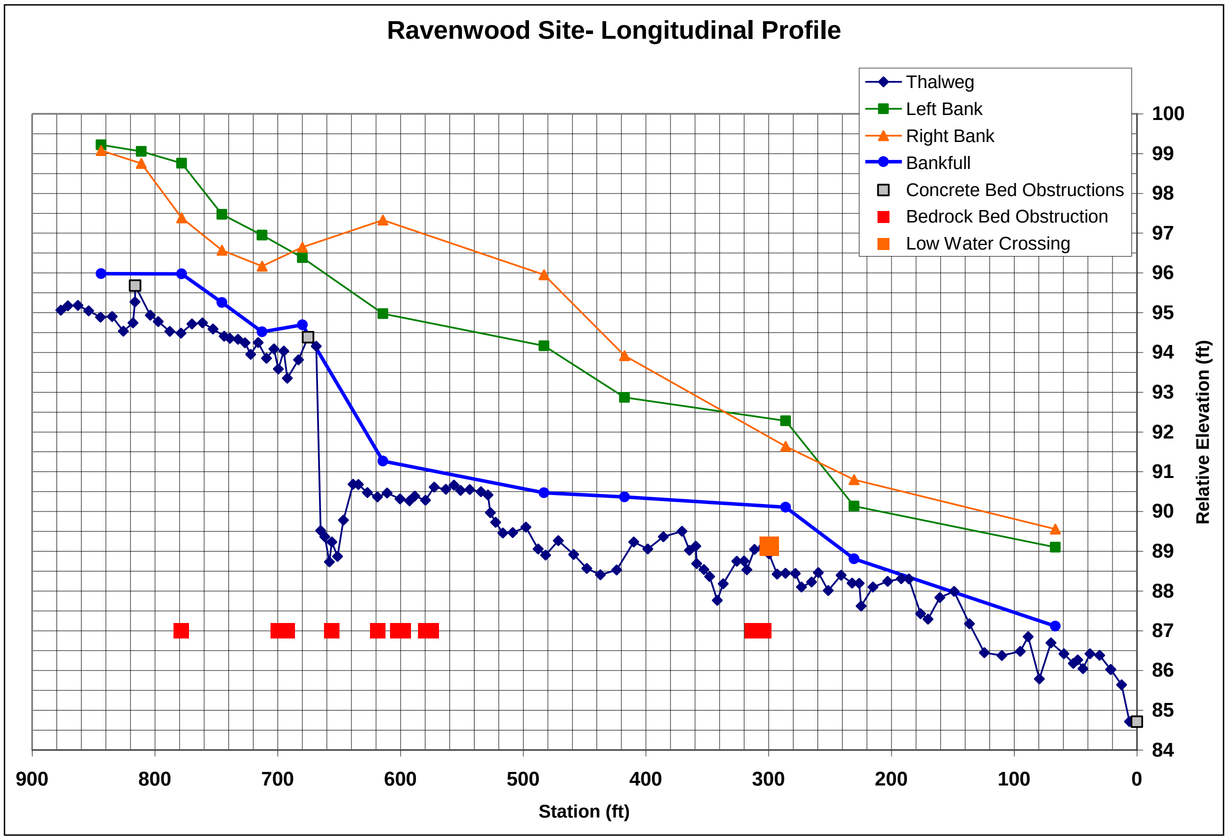


Figure 3: Longitudinal Profile

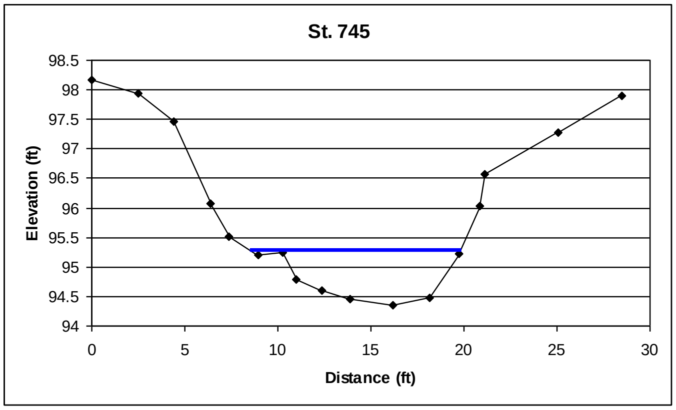


Figure 4a: Cross-section in Subreach #1.

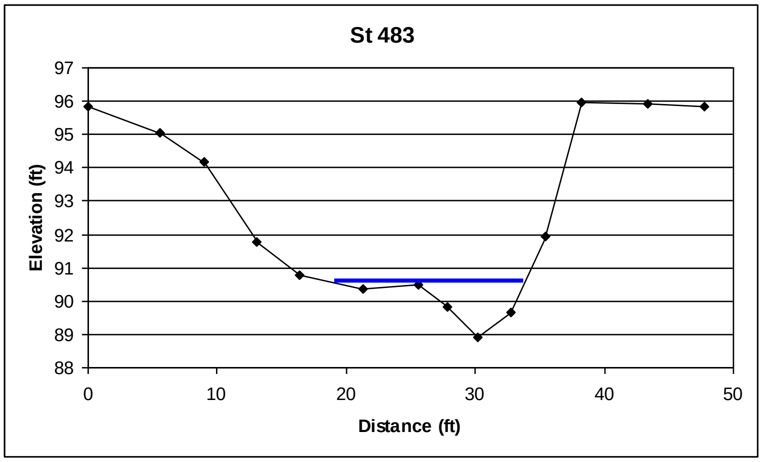


Figure 4b: Cross-section in Subreach #3.

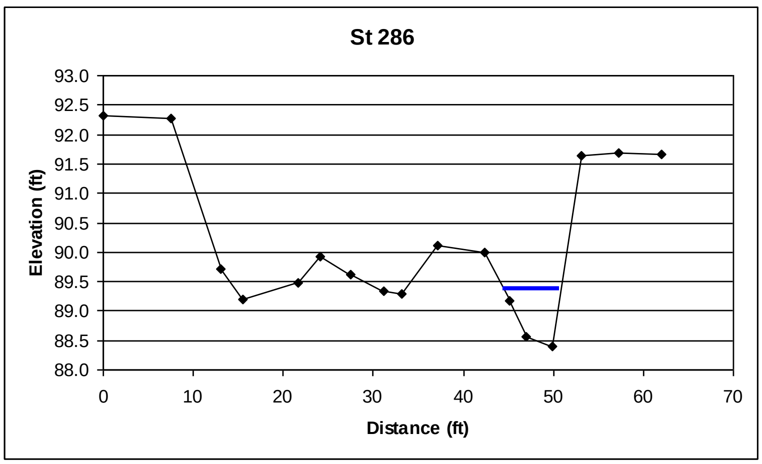


Figure 4c: Cross-section in Subreach #4a.

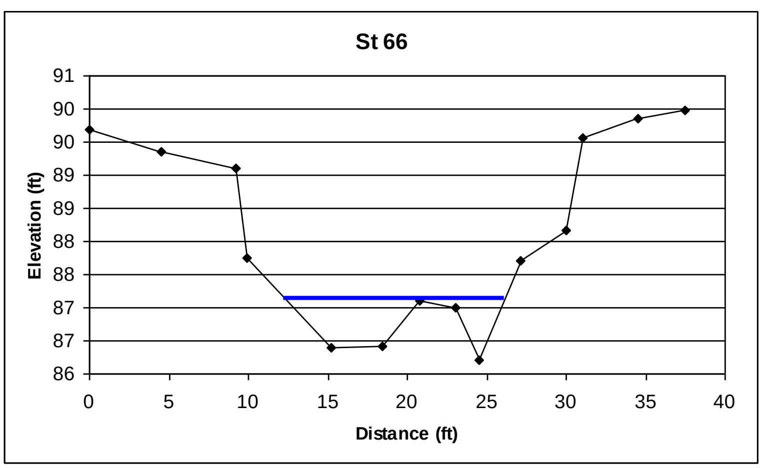


Figure 4d: Cross-section in Subreach #4b.

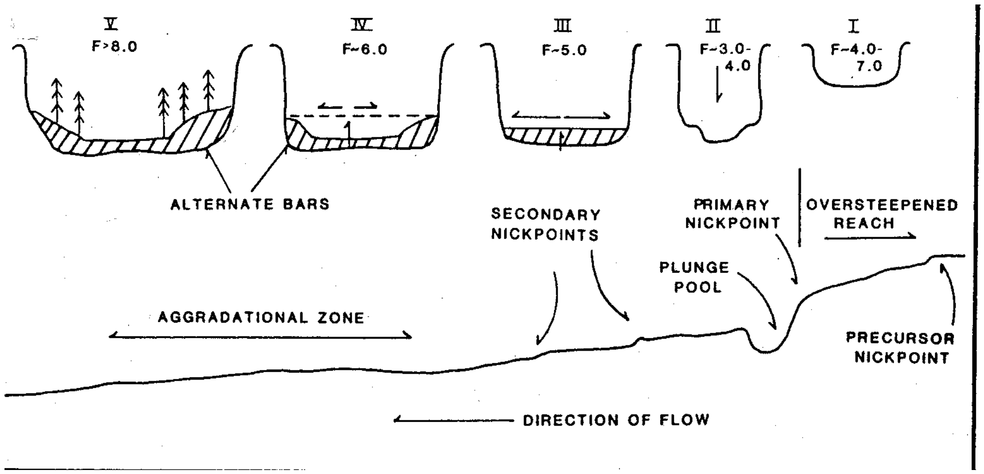


Figure 5: Idealized Headcut Profile and Cross-section (after Schumm et al. 1987).

"F" refers to the width/depth ratio of the channel cross-section. Project reach classification relates to the channel sections above as follows: I=subreach #1; II=subreaches #2A and 2B; II+III= subreach #2C; III=subreach 3; and IV+V=subreaches 4A and 4B.

Picture 1 – Looking upstream at 800ft (sub-reach #1)

Picture 2 – Concrete bed obstruction/headcut at 670ft (looking upstream)

Picture 3 – Bedrock exposure and bank artifacts on the right side at 600ft (sub-reach #1)

Picture 4 – Historical wagon(?) artifacts buried in alluvium at 615ft.

Picture 5 – Bedrock exposure at 550ft (sub-reach 2b-c)

Picture 6 – Eroding bank along long bend at 500ft (sub-reach #3)

Picture 7 – Point bar on left (under leaves) at 450ft (lower end of sub-reach #3)

Picture 8 – Eroding bank at 400ft (sub-reach #3)

Picture 9 – Slumping, failing bank just above stream crossing at ~320ft (Sub-reach #4)
Notice: Maybe old channel bed deposits collapsing into the present channel.

Picture 10 – Stream crossing at ~310ft (sub-reach #4a)

Picture 11 – Lower channel banks at 300ft (sub-reach #4)

Picture 12 – Wide and shallow channel with "double thalweg" at 200ft (sub-reach #4)

Picture 13 – Lower on of “double thalweg” at 100ft (sub-reach #4b)

Picture 14 – Concrete bed obstruction marking end of study reach at 0ft

Picture 15 – Engineered channel -140ft downstream of 0ft on survey (end of sub-reach #6)

Picture 16 - Bankfull channel section at 76 ft (taken April, 29, 2008).

Picture 17 - Bankfull channel section at 124 ft (4-29-08)

Picture 18 - Bankfull channel section at 156 ft(4-29-08)

Picture 19 - Bankfull channel section at 205 ft (4-29-08)

Picture 20 - Bankfull channel section at 240 ft (4-29-08)

Picture 21 - Bankfull channel section at 296 ft (4-29-08)

Picture 22 - Typical mixed gravel bed (4-29-08)

Picture 23 - Fine gravel deposits on a bar tail (4-29-08)

Picture 24 - Scour pool around a tree root at 310 to 340 ft (4-29-08)

Picture 25 - Imbricated cobbles indicating the elevation of the bed of a pre-settlement paleo-channel (4-29-08)

Picture 26 - Grass channel (SR #1) (4-29-08)

Picture 27 - Grass channel bed-upstream (4-29-08)

Picture 28 - Grass channel bed-downstream (4-29-08)

Picture 29 - Plunge pool (SR #2a+b) (4-29-08)

Picture 30 - Exposed phone line (4-29-08)

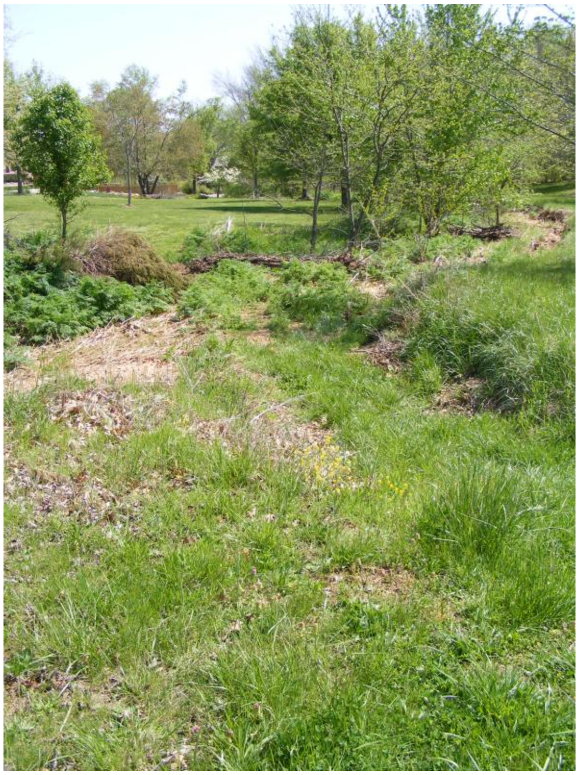
Picture 31 - Scoured residuum in plunge pool (4-29-08)

Picture 32 – Lower portion of sub-reach #2 (4-29-08)

Picture 33 - Upper sub-reach #3 (4-29-08)

Picture 24 - Lower sub-reach #3 (4-29-08)

Picture 35 - Upper sub-reach #4 (4-29-08)



Picture 36 - Road crossing (SR #4) (4-29-08)

Picture 37 - Lower Sub-reach #4 (4-29-08)

Picture 38 - End of Sub-reach #4 (4-29-08)

Picture 39 - Sub-reach #5 (4-29-08)