Hydrogeomorphic Assessment Report

Wolf Run Watershed
Fayette County, Kentucky

Prepared for
Kentucky Division of Water
200 Fair Oaks Lane
Frankfort, KY 40601

and

Lexington-Fayette Urban County Government
Division of Environmental Quality

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I. INTRODUCTION

This report summarizes results for the hydrogeomorphic assessment in the Wolf Run watershed. The survey was conducted under a Section 319(h) Nonpoint Source Implementation Program Cooperative Agreement (#C9994861-09) awarded by the Commonwealth of Kentucky, Energy and Environment Cabinet, Department for Environmental Protection, Division of Water (KDOW) to Lexington-Fayette Urban County Government (LFUCG) based on an approved work plan. The assessment was conducted by Third Rock staff, according to the pre-approved *Quality Assurance Project Plan* (QAPP, Third Rock 2011).

Development within the Wolf Run watershed has affected the stream geomorphology, altering watershed hydrology and sediment-transport patterns. The large amount of impervious surface has greatly reduced the capacity of the watershed to capture and filter rainfall. Higher runoff rates mean that runoff reaches the stream channels more quickly (flashier flows) and peak discharge rates are higher compared to an undeveloped watershed for the same size rainfall event. These effects are known as hydromodification.

Hydromodification can also be direct modification of a stream (for purposes of flood control, navigation, sediment control, infrastructure protection, etc.), such as channelization, armoring, and removal of riparian vegetation. Channel erosion and bank failure is often caused or exacerbated by hydromodification activities.

The hydrogeomorphic assessment was intended to measure channel changes in representative reaches in order to determine the effects of hydromodification including bed and bank erosion, sedimentation, and habitat loss. The relative potential for improvement was qualitatively assessed based on the lack of obvious physical constraints in a reach, position in the landscape, or position in the watershed. In total, the assessment aids in identification of areas where hydromodification is a problem and where solutions may be targeted.

II. METHODS

Nine hydrogeomorphic monitoring sites were selected throughout the watershed. Quantitative data were collected at each site to measure channel change in representative reaches as shown in Exhibit 1, page 2, and summarized in Table 1. Assessment included a series of spatially integrated, high-resolution cross-section and longitudinal profile surveys and streambed substrate evaluation to determine the extent of the effects of hydromodification in the Wolf Run watershed.

TABLE 1 – MONITORING LOCATIONS

Site Name	Stream	Location	Latitude	Longitude
W1	Wolf Run	Old Frankfort Pike	38.065675	-84.553357
W2	McConnell Branch	Preston's Cave	38.057364	-84.542765
W4	Vaughn's Branch	Valley Park	38.054974	-84.54985
W5A	Cardinal Run	Parkers Mill Road	38.044018	-84.557169
W6	Wolf Run	Wolf Run Park	38.046058	-84.550868
W7	Vaughn's Branch	Pine Meadow Park	38.031222	-84.539303
W8	Vaughn's Branch	Picadome Golf Course	38.037643	-84.526807
W9	Wolf Run	Faircrest Drive	38.031222	-84.539303
W11	Big Elm Tributary	Harrodsburg Road	38.031302	-84.52598

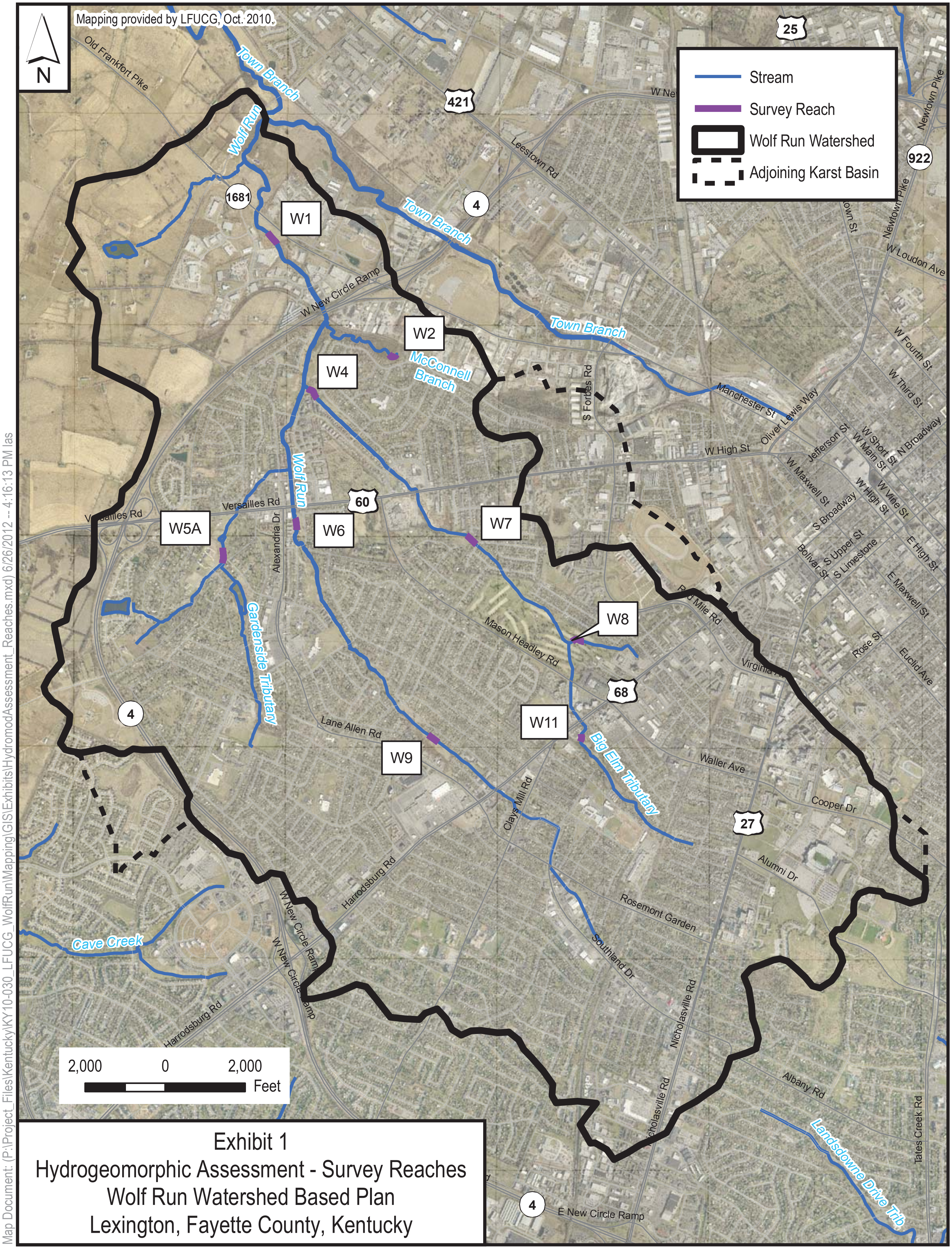


Exhibit 1
Hydrogeomorphic Assessment - Survey Reaches
Wolf Run Watershed Based Plan
Lexington, Fayette County, Kentucky

Permanent monuments consisting of rebar (0.75-inch rebar or similar material approximately 4 feet long) concreted within a plastic pipe casing were installed at the most permanent cross-section survey sites, unless it was not feasible due to site constraints. Otherwise, monuments of rebar without the casing or other permanent monuments were used. A monument was typically installed on both the right and left stream banks at least 10 ft back from the top of bank, indicating the extent of the measured cross-section and serving as surveying benchmarks. The monuments were not removed following the Year 2 measurements. To facilitate profile relocation during the second surveying period, the following actions were taken in the field:

1) Monuments were marked with a piece of flagging or paint,
2) GPS points were recorded at monuments and any other locations that would aid in site relocation,
3) Photographs were taken (for both relocation and to document the current site conditions), and
4) Notes were recorded on site identification characteristics (*e.g.,* bank condition, distinguishing landmarks/features, and other pertinent data).

The methods for each of these sampling efforts are described below.

A. Cross-Sections

Cross-sections surveyed were located within riffle features and identified by permanent monuments. Points were taken frequently at horizontal stations within each cross-section such that the surveying indicated all significant breaks in slope and provides a thorough characterization of each cross-section (refer to Harrelson *et al.* 1994 for surveying procedures). Equipment used included a 50- or 100-ft surveying tape, laser level (leveling accuracy < +/- 3mm/30m) on a tripod, and surveying rod. Data was recorded in RiverMorph™ software using a Rugged Reader Pocket PC or in a field notebook. All cross-section surveying data was reduced, plotted, and saved in a spreadsheet. Surveying precision was +/- 0.01 ft for vertical readings and +/- 0.1 ft for horizontal readings. Notes related to observed changes at various elevations within the cross-section were made. Each stream permanent cross-section was surveyed twice, once at the initial site visit following monument installation and at least nine months subsequent to first measurement. Differences between these two measurements allowed estimation of channel change and determination if degradation (or aggradation) is occurring.

B. Longitudinal Profiles

Representative stream longitudinal profiles were taken over a distance that included approximately three riffle features, where present, at each of the nine hydrogeomorphic monitoring stations. Permanent monuments on a designated bank and at least 10 feet back from the top of bank marked the upstream and downstream extents of the profiles and served as benchmarks for surveying. Profile measurements were taken within the stream thalweg and at a frequency to identify all grade changes and facet slopes within the profile (refer to Harrelson 1994 for surveying procedures). Equipment used included a 100-ft surveying tape, laser level (leveling accuracy < +/- 3mm/30m) on a tripod, and surveying rod. Data was recorded in a field notebook. All profile surveying data was reduced, plotted, and saved in a spreadsheet. Surveying precision shall be +/- 0.01 ft for vertical readings and +/- 0.1 ft for horizontal readings. Locations of permanent cross-sections were indicated within the recorded profiles. Each stream profile was surveyed twice, once at the initial site visit following monument installation and at least nine months subsequent to first measurement. Differences between these two measurements allowed estimation of changes to channel bed elevation and facet characteristics.

C. Pebble Counts

Reach-wide pebble counts were collected within the stream where the longitudinal profiles are taken at the nine hydrogeomorphic monitoring sites. If substrate did not appear similar in all riffles, riffles with considerably coarser substrate that could be indicative of a large rock fall or channel armoring were avoided. Each reach pebble count sampled within the riffles and pools proportional to the length of the reach comprised of riffles and pools. Riffle and pool data were kept separate. For the reach-wide pebble counts, particle sampling was completed along evenly spaced transects over the entire bankfull width and consisted of at least 100 particles, and more particles were collected for the reach-wide pebble count at most sites to ensure accurate representation of the wide particle-size spectrums observed (refer to Rosgen 2008 and Bunte and Abt 2001 for pebble count procedures). An active bed, riffle pebble count was collected within the permanent cross-section at each of the nine hydrogeomorphic monitoring sites. For the active riffle bed count, particle sampling will be completed along evenly spaced transects over the active bed width and consist of at least 100 particles (refer to Rosgen 2008 and Bunte and Abt 2001 for pebble count procedures). For all pebble counts, each transect started on the same side of the stream and collection moved from downstream to upstream. Sampling points were spaced by at least the D_{max} particle size. The pebble counts ended at the extent of a given transect, not in an arbitrary location when a count of 100 particles is reached. If fine sediments (sand/silt) were encountered and the thickness of the sediment layer was less than 0.5 inch, then the larger particle below the fines was selected. Otherwise the observation was counted as fines (*i.e.,* less than or equal to 2mm). Measurements were madding with a gravelometer (gravel template). Data was predominately recorded in RiverMorph™ software using a Rugged Reader Pocket PC, but a Pebble Count Datasheet was used in some instances. Particle distributions were plotted and statistics calculated in RiverMorph™. Precision for pebble count readings was such that each data point measured within +/- 1 units of the narrative particle description or +/- 0.5 phi units on the gravelometer. Each pebble count was performed twice, once at the initial site visit and at least nine months subsequent to first measurement. For each sampling event, particle size distributions and D_{50} values were computed and differences between these two measurements were reviewed to identify changes to channel substrate.

III. RESULTS

A. General

The nine hydrogeomorphic monitoring sites (Table 1, page 1; Exhibit 1 page 2) represent stream reaches that are susceptible to the effects of hydromodification. These areas are in need of management to stop further degradation, and would be good locations to implement remediation. The nine sites include near the mouth of the Wolf Run Watershed (W1), McConnell Branch tributary downstream of Preston's Cave (W2), Vaughn's Branch tributary adjacent to Valley View Park (W4), Cardinal Run tributary within private property off of Parkers Mill Road (W5A), Wolf Run between Wolf Run Park and several apartment buildings (W6), Vaughn's Branch tributary within Pine Meadow Park (W7), Vaughn's Branch tributary within Picadome Golf Course (W8), Wolf Run between the Allendale Drive Greenway and several residences (W9, accessed from Faircrest Drive), and the Big Elm tributary accessed off Harrodsburg Road (W11, West of Bob O Link Drive), The sites are distributed such that typical conditions of Wolf Run and its tributaries were evaluated, rather than the worst conditions within stream. Appendix A includes pictures from each site, including the above-mentioned, concreted, channelized portions of Wolf Run that were not characterized by this assessment.

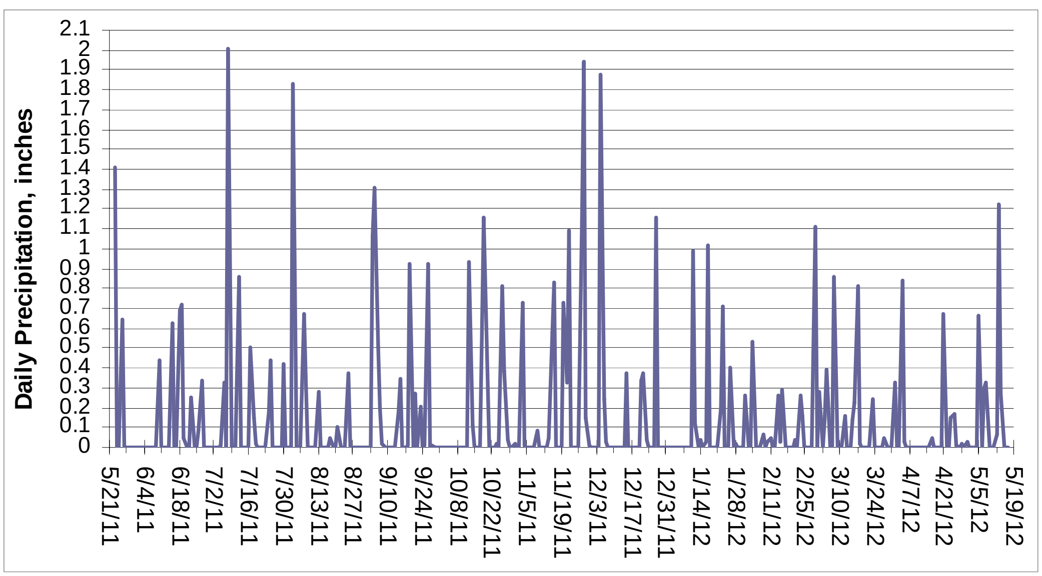
Because the most upstream segment of Wolf Run, upstream from approximately Clays Mill Road, is heavily modified, it was excluded from the assessment. This segment of Wolf Run is either paved/armored or confined by bedrock and therefore the physical channel character was not expected to change during the monitoring period.

At each site, the stream permanent cross-section, longitudinal profile, and substrate (through pebble counts) was surveyed twice, once at the initial site visit following monument installation and at least nine months subsequent to first measurement. Table 2 summarizes the survey dates at each site. During the monitoring period, many flow-producing rainfall events occurred, thus many events with potential to produce stream erosion occurred. Figure 1 indicates the frequency and amount of precipitation that occurred during the monitoring period; the amount of precipitation during the assessment was above average. Additionally, in-stream water level monitoring performed during another study indicates that flows were observed above the top of bank for sites W6 and W11 during the monitoring period (Evans 2012). Water levels were observed within a half-foot or less to the top of bank at sites W2, W4, and W9. Water levels were not monitored by the study for sites W5A, W7, or W8.

TABLE 2 – MONITORING DATES

Site	First Survey	Final Survey
W1	6/21/2011	3/16/2012
W2	5/26/2011	4/9/2012
W4	6/14/2011	5/17/2012
W5A	5/26/2011	3/16/2012
W6	6/17/2011	3/14/2012
W7	6/14/2011	3/13/2012
W8	6/22/2011	4/10/2012
W9	5/23/2011	3/15/2012
W11	5/24/2011	3/15/2012

FIGURE 1 – PRECIPITATION DURING MONITORING PERIOD



NOTE: Precipitation values based on KLEX weather station data from http://www.wunderground.com.

Table 3 summarizes general characteristics observed for the surveyed reaches at each site. The surface drainage areas for each monitoring location ranged from 92 acres at McConnell Branch (W2) to more than 6,000 acres at the most downstream monitoring site on Wolf Run (W1). Subsurface drainage area (misbehaved karst) does contribute runoff to sites W1, W2, and W5A. More detail can be found regarding the karst influences throughout the watershed in the Karst Hydrograph Characterization Report (Evans, 2012). A total of 3,024 feet of stream were surveyed across the nine sites (about 4% of the total length in the watershed), with an average length of 336 feet surveyed per site. The Big Elm Tributary (W11) was the steepest reach surveyed (1.1% slope) and the most downstream station of Wolf Run (W1) had the lowest slope (0.25%). The average channel width (at top of low bank) for the three Wolf Run reaches was 44.3 feet while the average width of the tributaries was narrower at 29.1 feet. The average channel cross-sectional area (at top of low bank) for the three Wolf Run reaches was 98.8 square feet while the tributaries averaged 64.6 square feet. Comparing the measured cross-sectional area and width to values predicted by regional curves for each site given the surface drainage area indicates that the streams assessed are over-widened and entrenched, such that the channel width and area are larger than expected for relatively unimpacted streams in the Bluegrass physiographic region (Parola 2007). Subsurface drainage area (misbehaved karst) does contribute runoff to sites W1, W2, and W5A that is not included in the drainage area used to predict bankfull channel characteristics with the Bluegrass regional curve.

TABLE 3 – GENERAL SITE CHARACTERISTICS

Site	Stream	Surface Drainage Area (ac)	Surveyed Profile Length (ft)	Average Channel Slope (%)	In Permanent Cross-Section (Riffle)		Predicted Bankfull Channel Width by Bluegrass Regional Curve (ft)	Predicted Bankfull Channel Area by Bluegrass Regional Curve (ft^2)
					Channel Width at Top of Low Bank (ft)	Channel Area at Top of Low Bank (ft^2)		
W1	Wolf Run	6,139	400	0.25%	49.6	155.8	32.5	72.3
W2	McConnell Branch	93	363	0.65%	23.5	26.1	4.3	1.1
W4	Vaughn's Branch	1,868	412	0.64%	29.4	93.2	18.3	22.3
W5A	Cardinal Run	689	400	0.67%	12	10.7	11.4	8.3
W6	Wolf Run	2,313	300	0.33%	41.1	84.9	20.3	27.5
W7	Vaughn's Branch	1,520	339	0.61%	44	109.1	16.6	18.2
W8	Vaughn's Branch	1,494	338	0.80%	31.5	74	16.5	17.8
W9	Wolf Run	510	300	0.85%	42.3	55.6	9.8	6.2
W11	Big Elm Tributary	518	172	1.10%	34.2	74.7	9.9	6.2

B. Aquatic Life and Habitat

The *Habitat and Macroinvertebrate Assessment Report* (Olson 2011) includes benthic macroinvertebrate sampling and stream habitat evaluations of the same general reaches as this assessment. Habitat assessments performed for that study were intended to supplement the biological and physicochemical data when determining the overall health of the stream reaches and to provide a baseline to document physical changes that occur over time and to identify potential areas for BMP implementation. This information is relevant to this assessment as well since it is another indicator of the physical condition of these stream reaches.

Macroinvertebrate biotic indices (MBI) were calculated in the vicinity of six of the hydrogeomorphic monitoring sites (W1, W2, W4, W5A, W6, W11) and all results indicated "poor" classifications. For each of the sites, the abundance of clingers (taxa requiring stable substrates to cling to, such as gravel, boulders, root wads, etc) was very low, which is frequently an indicator of unstable substrate or high levels of siltation or embeddedness.

For the habitat assessments, this study assessed 33 reaches, including reaches in the vicinity of the hydrogeomorphic monitoring sites. For each reach corresponding to a hydrogeomorphic monitoring sites, the habitat score was "poor". The habitat score for the reach corresponding to site W2 (McConnell Branch at Preston's Cave) was on the threshold between "fair" and "poor", with marginal sediment deposition and embeddedness scores causing the poor rating at the site. Each of these streams has low scores across all parameters. The riparian zone width was routinely the lowest overall parameter. Low scores for epifaunal substrate / available cover, embeddedness, and velocity depth regime together suggest that little habitat is available for macroinvertebrates due to an lack of pools and available cobble habitat in the stream.

C. Cross-Sections

Figures 2 through 10, pages 8 through 12, show the measured riffle cross-sections for each site for 2011 and 2012. Each graph uses generally the same magnitude for scale of the x and y axes so that comparisons of the relative size of each stream channel can be made. Generally, the graphs indicate that each permanent cross-section was rather stable over the monitoring period, though areas of erosion and/or aggradation were measured at each site. For example, Figure 2 shows some erosion at the toe of the slope on the left, descending bank at site W1. Observations and photographs indicate that some of the lateral bank movement indicated by the cross-section data may be due to measurement errors, though care was taken to make measurements between the permanent monuments. Photographs of each permanent cross-section for both monitoring years are included in Appendix A.

FIGURE 2 – W1 (WOLF RUN) PERMANENT CROSS-SECTION

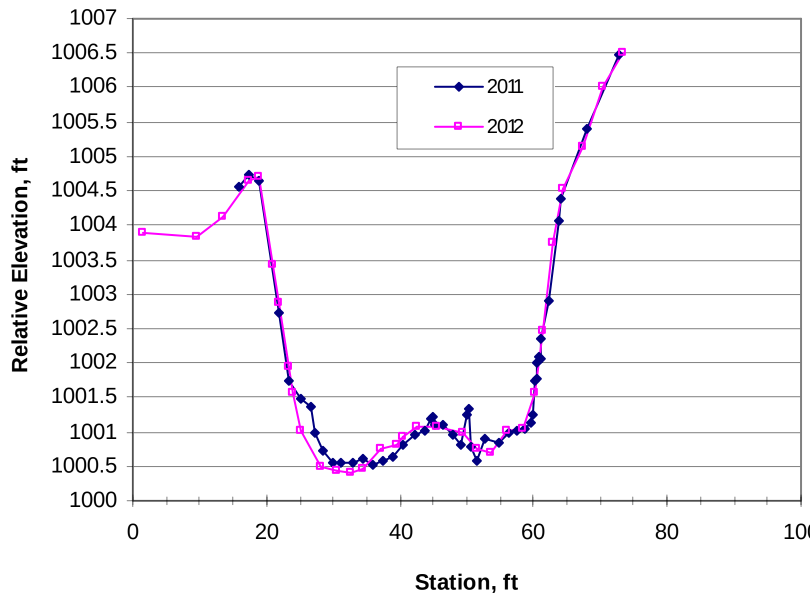


FIGURE 3 – W2 (MCCONNELL BRANCH) PERMANENT CROSS-SECTION

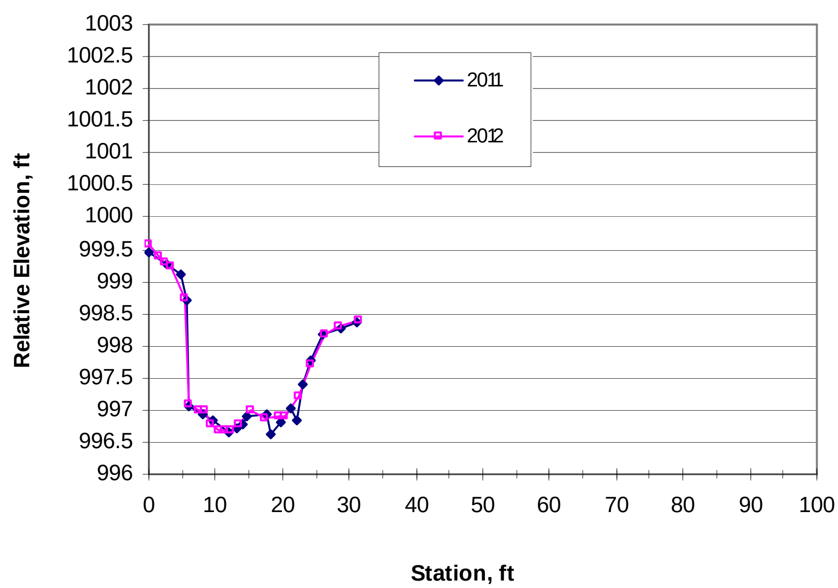


FIGURE 4 – W4 (VAUGHN'S BRANCH) PERMANENT CROSS-SECTION

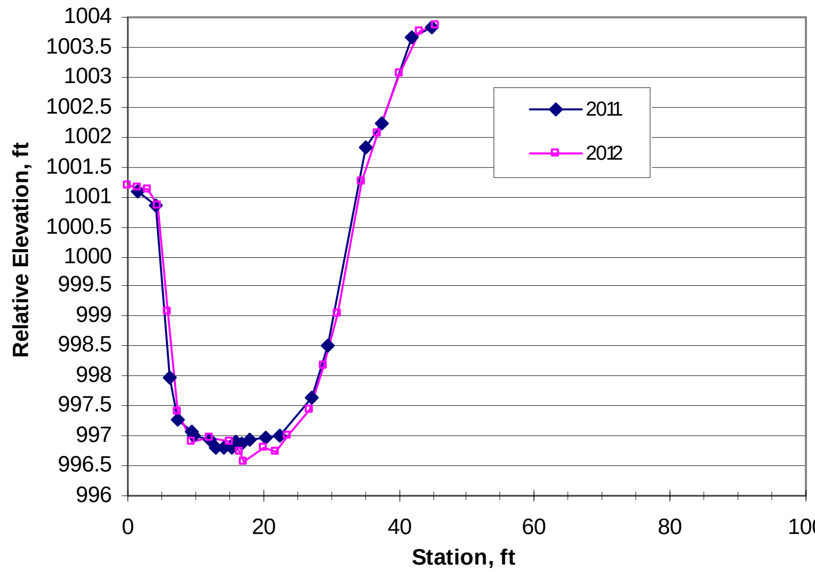


FIGURE 5 – W5A (CARDINAL RUN) PERMANENT CROSS-SECTION

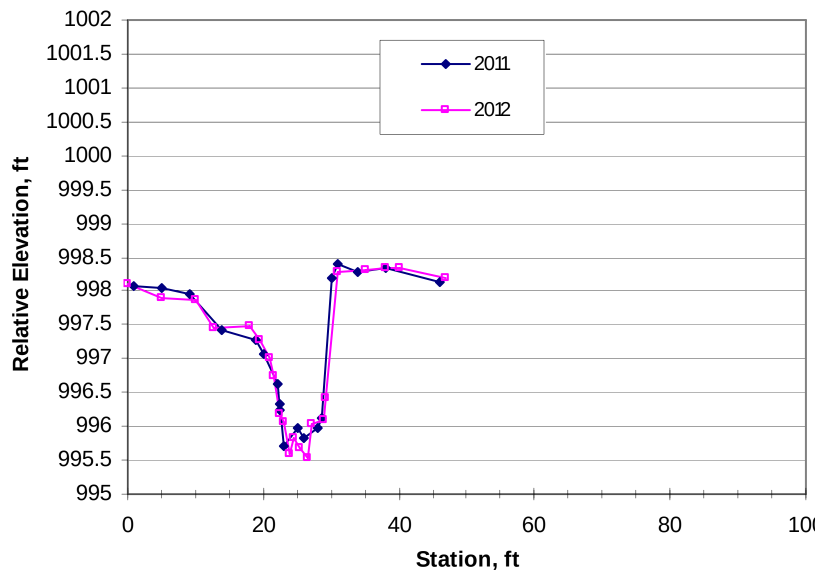


FIGURE 6 – W6 (WOLF RUN) PERMANENT CROSS-SECTION

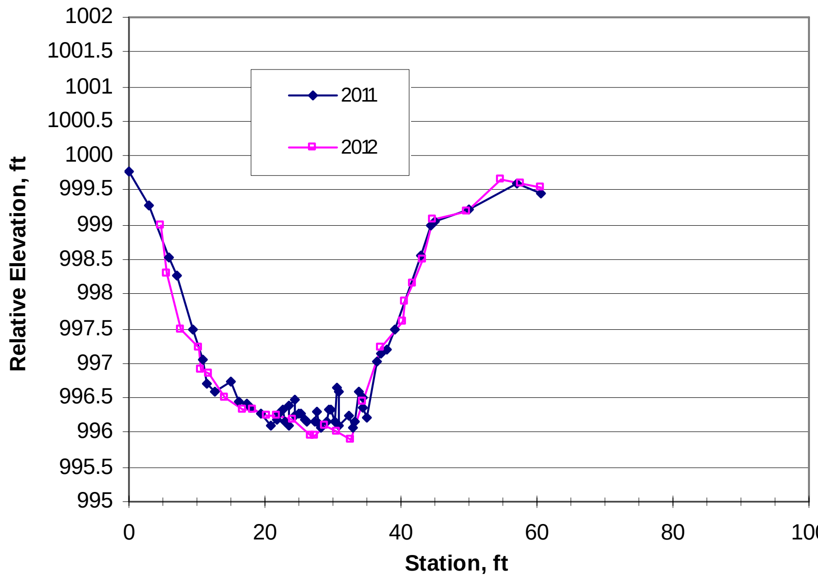


FIGURE 7 – W7 (VAUGHN'S BRANCH) PERMANENT CROSS-SECTION

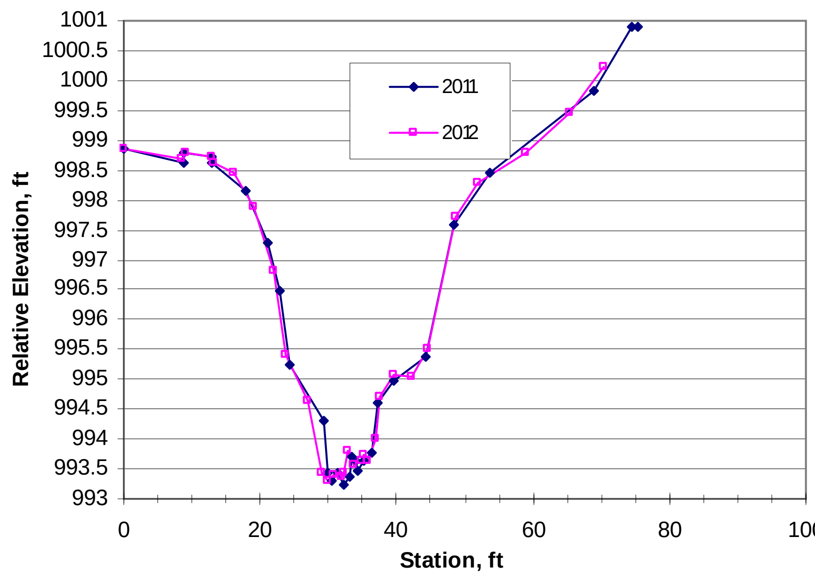


FIGURE 8 – W8 (VAUGHN'S BRANCH) PERMANENT CROSS-SECTION

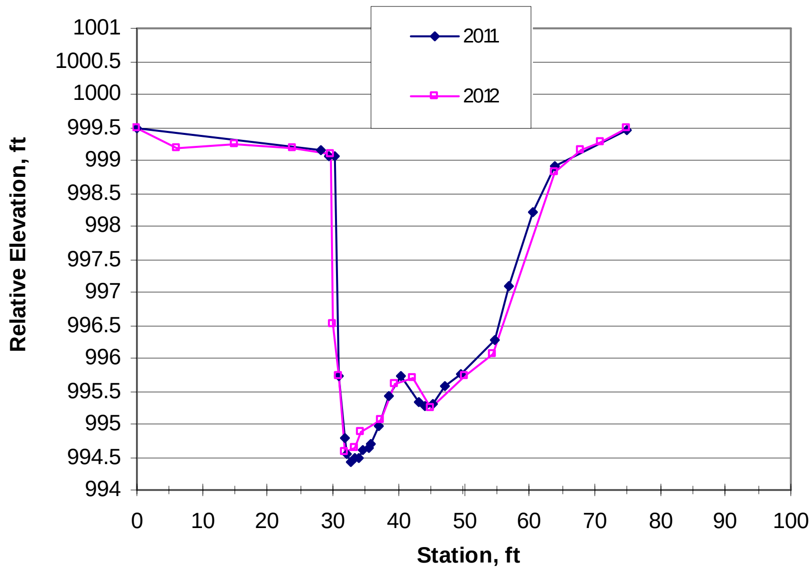


FIGURE 9 – W9 (WOLF RUN) PERMANENT CROSS-SECTION

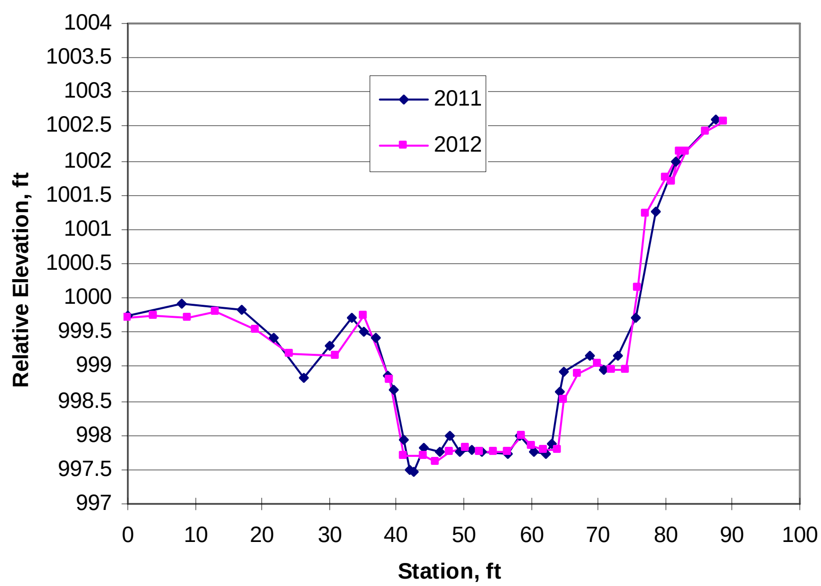
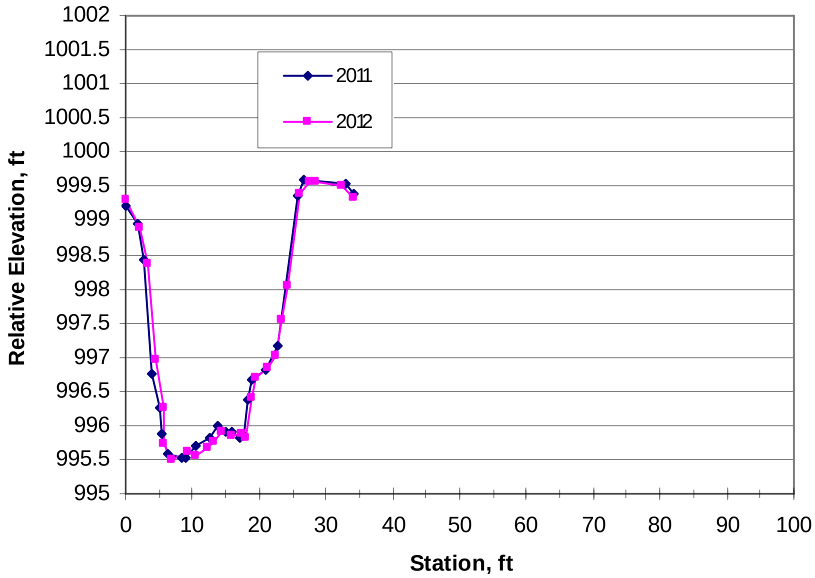


FIGURE 10 – W11 (BIG ELM) PERMANENT CROSS-SECTION



D. Longitudinal Profiles

Figures 11 through 19, pages 13 through 15, show the measured longitudinal profiles of the stream thalweg (deepest part of stream) for each site in 2011 and 2012. Each graph uses generally the same magnitude for scale of the x and y axes so that comparisons of the relative slope of each stream channel can be made. Generally, the graphs indicate that each surveyed profile was rather stable over the monitoring period, though small areas of downcutting and/or aggradation were measured at each site. The profile observed for Cardinal Run Tributary (W5A) indicates that the pool from approximately station 290 to 310 filled in roughly three inches due to deposition. This material was likely supplied by the deepening of the pool at station 16. Observations and photographs indicate that some of the changes or shifts in facet locations indicated by the profile data may be due to measurement errors, such as laying down the measuring tape along a different path within the stream (different estimate of thalweg) in the second year's survey. This is likely part of the reason for the differences observed in the profile from approximately station 160 to 265 at site W7 (Vaughn's Branch, Pine Meadow Park), though habitat and substrate assessments and qualitative observations indicate that the bed is rather mobile at site W7. Changes in the stream profile indicate aggradation at site W8 (Vaughn's Branch within Picadome Golf Course) from approximately station 144 to 191 and 301 to 325. This is reasonable considering the unstable nature of this highly impacted reach.

There is an absence of deep pool habitat in some reaches. The reach near the mouth of Wolf Run (W1) has some bedrock-dominated pools and a rather monotonous bed comprised of run/shallow pool habitat. Similarly, the most downstream reach of Vaughn's Branch surveyed (W4) contained on deep pool on bedrock, but the remainder of the reach is predominately riffle and run habitat. This lack of vertical diversity reduces niche habitats for aquatic life. Though the bed does appear rather mobile at sites W7 and W8 (both Vaughn's Branch), there is more diversity of the bed than observed for other sites. Distinct riffles and pools can be observed in Figures 16 and 17, though other factors such as poor riparian cover and bank instability reduce the habitat value within these reaches.

FIGURE 11 – W1 (WOLF RUN) LONGITUDINAL PROFILE OF STREAM THALWEG

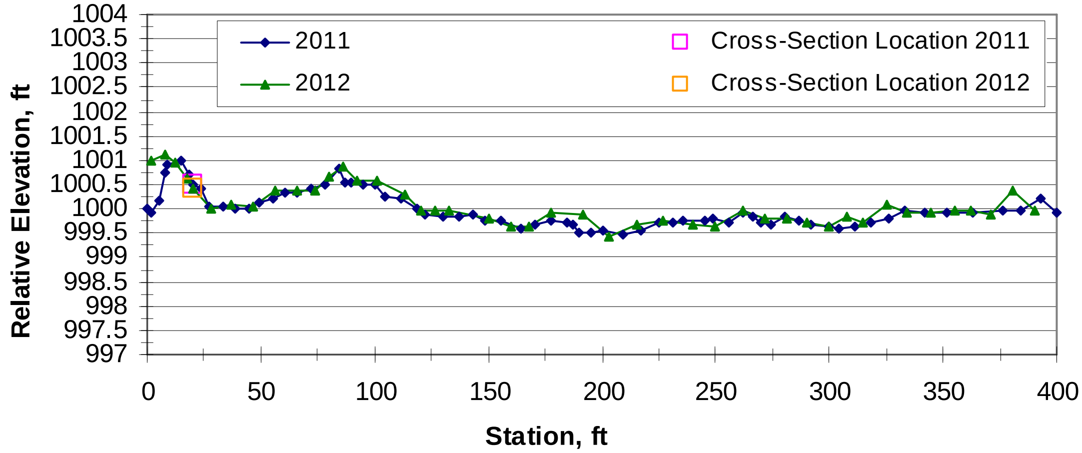


FIGURE 12 – W2 (MCCONNELL BRANCH) LONGITUDINAL PROFILE OF STREAM THALWEG

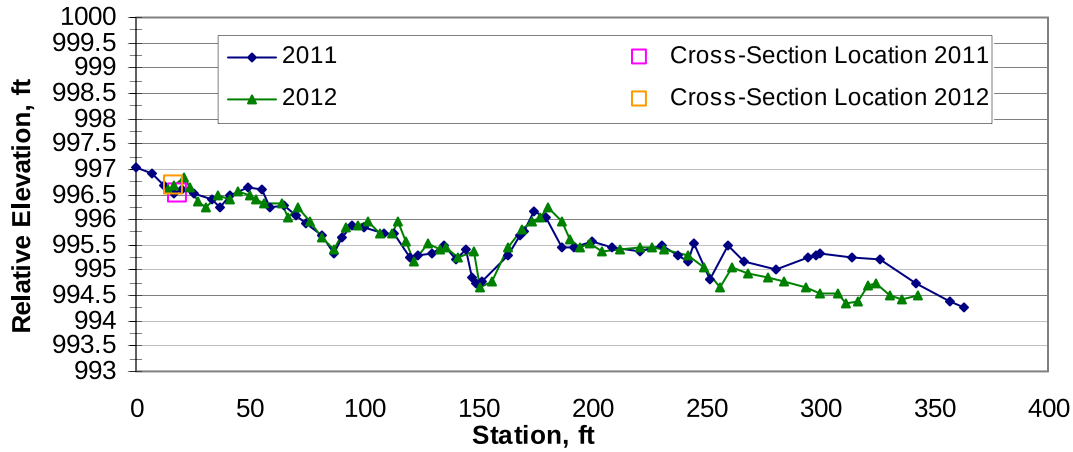


FIGURE 13 – W4 (VAUGHN'S BRANCH) LONGITUDINAL PROFILE OF STREAM THALWEG

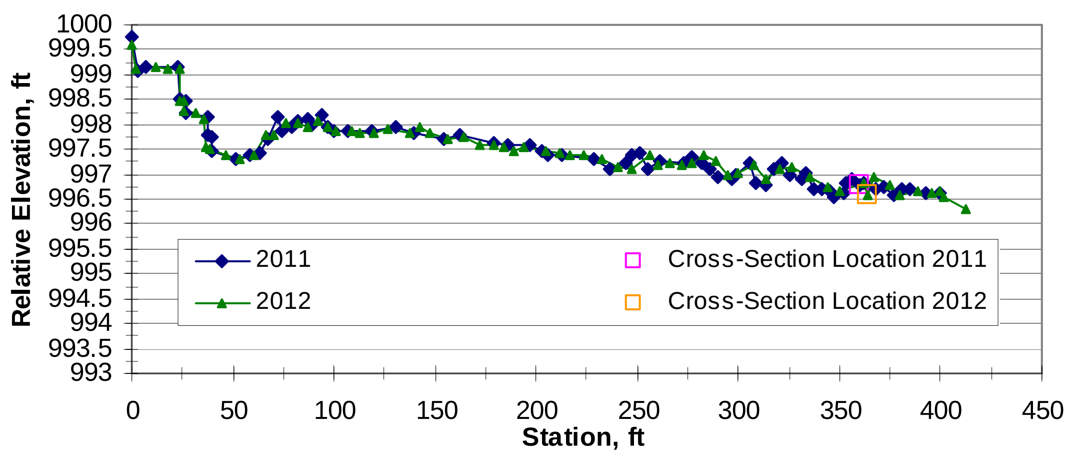


FIGURE 14 – W5A (CARDINAL RUN) LONGITUDINAL PROFILE OF STREAM THALWEG

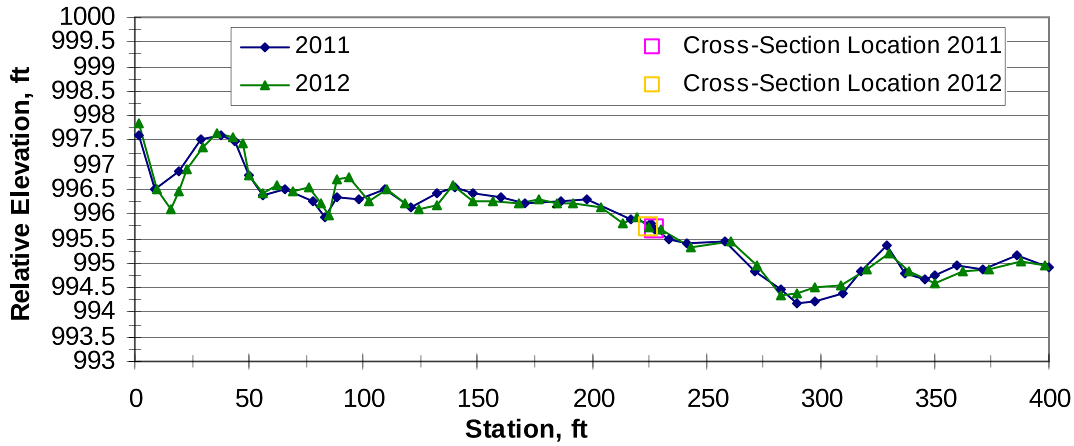


FIGURE 15 – W6 (WOLF RUN) LONGITUDINAL PROFILE OF STREAM THALWEG

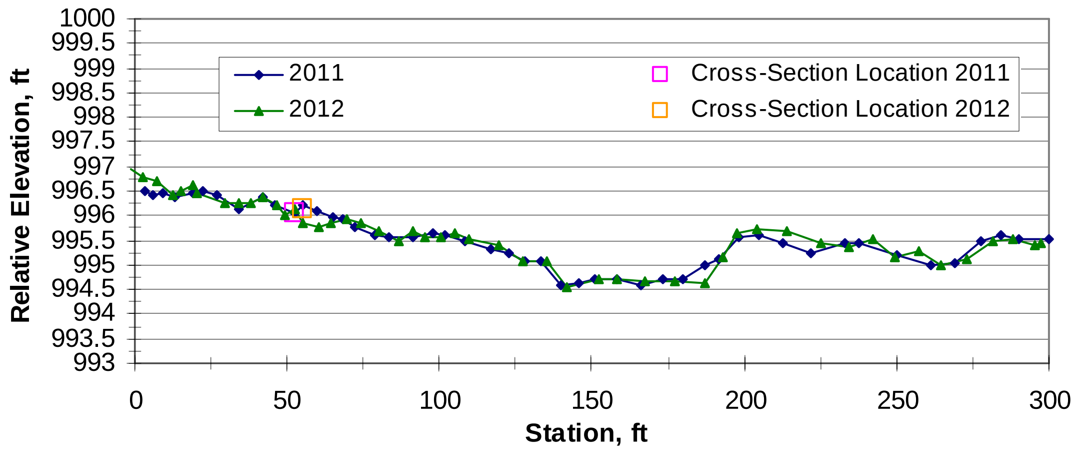


FIGURE 16 – W7 (VAUGHN'S BRANCH) LONGITUDINAL PROFILE OF STREAM THALWEG

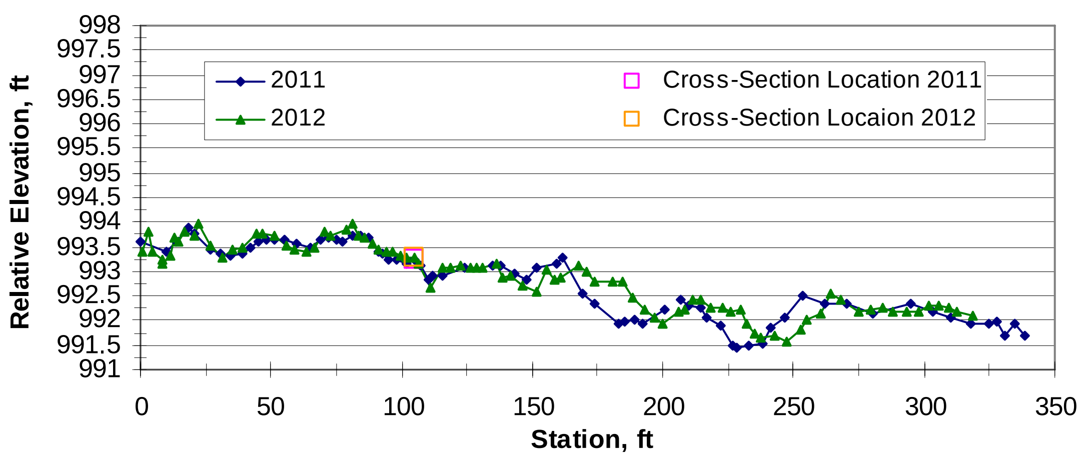


FIGURE 17 – W8 (VAUGHN'S BRANCH) LONGITUDINAL PROFILE OF STREAM THALWEG

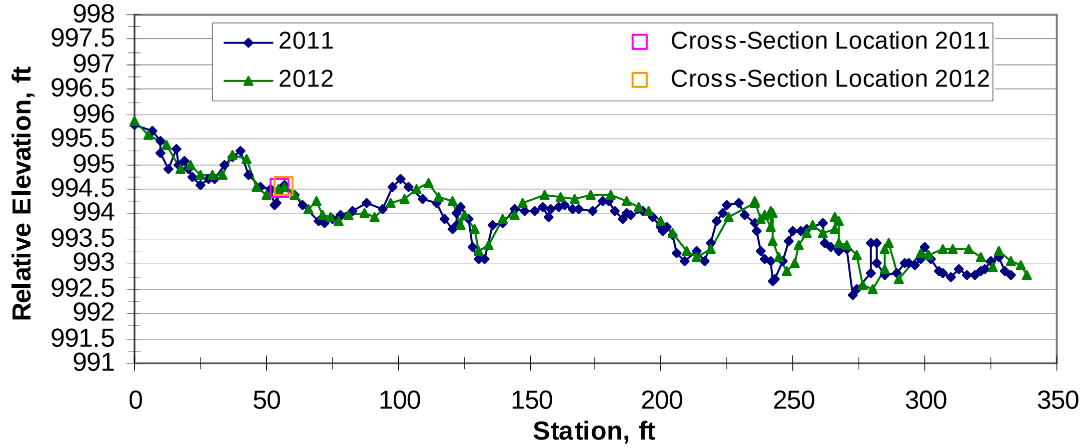


FIGURE 18 – W9 (WOLF RUN) LONGITUDINAL PROFILE OF STREAM THALWEG

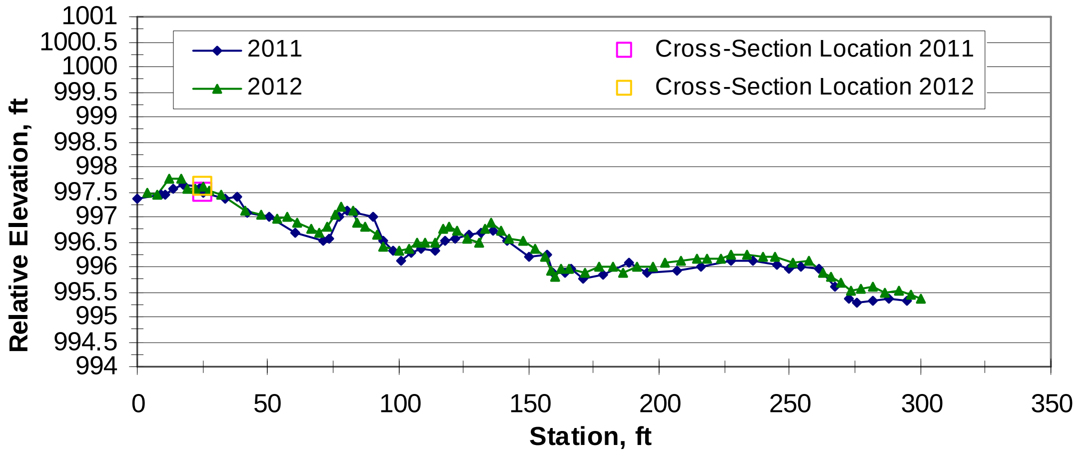
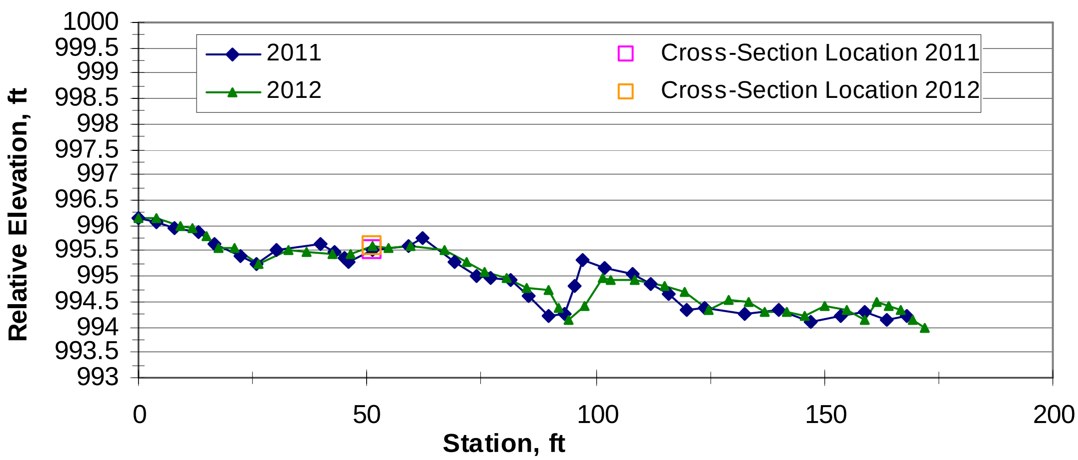


FIGURE 19 – W11 (BIG ELM) LONGITUDINAL PROFILE OF STREAM THALWEG



E. Pebble Counts

Table 4 summarizes the median particle size and description measured for the active riffle pebble count at the permanent cross-section location for both monitoring events. Comparing the data indicates large differences in the median values for 2011 and 2012. Observations at each site indicate that these differences are largely due to variability in the monitoring itself and not to actual substrate distribution changes. While this data is useful to indicate the magnitude of the substrate for each site, unfortunately it is not adequate to use to indicate a change in substrate size distribution over the monitoring period. The data indicates all of the reaches have median particles described as gravel, with the exception of site W5A (Cardinal Run). The bed at this site is very consolidated silt/clay material and provides poor aquatic habitat. The other sites in general have coarser substrate available to provide more aquatic habitat, but often this substrate is embedded or evidence of sedimentation was observed.

TABLE 4 – MEDIAN PARTICLE SIZE, ACTIVE RIFFLE, AND PREDICTED PARTICLE ENTRAINMENT FOR EACH SITE

Site Name	Stream, Location	2011		2012		D_{50} Mobile When Water at Top of Low Bank?
		Active Riffle D_{50}, mm*	Particle Size Description	Active Riffle D_{50}, mm*	Particle Size Description	
W1	Wolf Run, Old Frankfort Pike	30.8	Coarse Gravel	38.5	Very Coarse Gravel	Yes (Shields and Rosgen Curves)
W2	McConnell Branch, Preston's Cave	10.8	Medium Gravel	23	Coarse Gravel	Yes (Shields and Rosgen Curves)
W4	Vaughn's Branch, Valley Park	32	Coarse Gravel	17.7	Coarse Gravel	Yes (Shields and Rosgen Curves)
W5A	Cardinal Run, Parkers Mill Road	0.04	Silt / Clay	0.04	Silt / Clay	Yes (Shields and Rosgen Curves)
W6	Wolf Run, Wolf Run Park	45	Very Coarse Gravel	16.6	Coarse Gravel	Yes (Shields and Rosgen Curves)
W7	Vaughn's Branch, Pine Meadow Park	23	Coarse Gravel	19	Coarse Gravel	Yes (Shields and Rosgen Curves)
W8	Vaughn's Branch, Picadome Golf Course	14.2	Medium Gravel	31.4	Coarse Gravel	Yes (Shields and Rosgen Curves)
W9	Wolf Run, Faircrest Drive	50.7	Very Coarse Gravel	25.2	Coarse Gravel	Yes (Shields and Rosgen Curves)
W11	Big Elm Tributary, Harrodsburg Road	29.2	Coarse Gravel	13.7	Medium Gravel	Yes (Shields and Rosgen Curves)

*D_{50} is median particle size

For each permanent cross-section, basic calculations were performed to estimate shear stress when the water depth in the cross-section is at the top of the observed low bank. Regional curve estimates presented above in Table 3, page 6, indicate that the top of the observed low bank corresponds to a flow area greater than the bankfull area. In impaired streams, physical bankfull indicators such as well-developed floodplains, depositional features, breaks in slope, and changes in vegetation are not always present or reliable indicators of bankfull flow. Since field bankfull indicators were not observed in these reaches, shear and sediment transport was evaluated for water depth at the top of low bank elevation. These calculations were performed using the RiverMorph™ software, but the Shields equation for shear stress was used (Shields 1936),

$$\tau = \gamma RS$$

Where

τ = shear stress (lbs/ft^2);
γ = specific weight of water (lbs/ft^3);
R = hydraulic radius (ft); and
S = channel slope (ft/ft).

Computed shear stress values were compared to both Shields' and Rosgen's curves for grain diameter expected to be entrained versus shear stress (Rosgen 2008). The Rosgen curve generally indicates the mobility of larger particles for a given shear stress compared to the Shields curve. Table 4 above indicates whether the average D_{50} particles for the two data sets (2011 and 2012) are predicted to be mobile when water depth is at the observed top of low bank. The average D_{50} particle size is predicted to be mobile when water is at the top of the low bank for all sites.

Table 5, page 18, summarizes the 84th percentile particle size (D_{84}) and description measured for the active riffle pebble count at the permanent cross-section location for both monitoring events. Eighty-four percent of particles measured in the given pebble count are the size indicated in the table or smaller so this is an indication of the larger material in the active part of the riffle bed. Comparing the data indicates large differences in the median values for 2011 and 2012. Again, observations at each site indicate that these differences are largely due to variability in the monitoring itself and not to actual substrate distribution changes. While this data is useful to indicate the magnitude of the substrate for each site, unfortunately it is not adequate to use to indicate a change in substrate size distribution over the monitoring period. The data indicates all of the reaches have 84th percentile particles described as gravel or small cobble, with two exceptions. The 2011 measurement at site W5A (Cardinal Run) indicates the bed is very consolidated silt/clay material while the 2011 measurement at W6 (Wolf Run adjacent to Wolf Run Park) indicates bedrock was the 84th percentile particle. Frequent exposed bedrock is typical when streams in the Bluegrass physiographic region are incised; it does provide grade control but is poor for aquatic habitat.

TABLE 5 – 84TH PERCENTILE PARTICLE SIZE, ACTIVE RIFFLE, AND PREDICTED PARTICLE ENTRAINMENT FOR EACH SITE

Site Name	Stream, Location	2011		2012		D_{84} Mobile When Water at Top of Low Bank?
		Active Riffle D_{84}, mm	Particle Size Description	Active Riffle D_{84}, mm	Particle Size Description	
W1	Wolf Run, Old Frankfort Pike	208.9	Large Cobble	110	Small Cobble	No
W2	McConnell Branch, Preston's Cave	33.8	Very Coarse Gravel	58.9	Very Coarse Gravel	Yes (Rosgen Curve Only)
W4	Vaughn's Branch, Valley Park	104.3	Small Cobble	64.2	Small Cobble	Yes (Rosgen Curve Only)
W5A	Cardinal Run, Parkers Mill Road	0.06	Silt / Clay	6.5	Fine Gravel	Yes (Shields and Rosgen Curves)
W6	Wolf Run, Wolf Run Park	Bedrock	Bedrock	84.6	Small Cobble	Yes (Shields and Rosgen Curves for 2012 value)
W7	Vaughn's Branch, Pine Meadow Park	46.7	Very Coarse Gravel	50.8	Very Coarse Gravel	Yes (Shields and Rosgen Curves)
W8	Vaughn's Branch, Picadome Golf Course	27.3	Coarse Gravel	67.2	Small Cobble	Yes (Shields and Rosgen Curves)
W9	Wolf Run, Faircrest Drive	121.3	Small Cobble	74.7	Small Cobble	Yes (Rosgen Curve Only)
W11	Big Elm Tributary, Harrodsburg Road	71.8	Small Cobble	49.5	Very Coarse Gravel	Yes (Shields and Rosgen Curves)

The initiation of sediment transport in natural streams is complex, particularly in streams with a mixture of bed material grain sizes such those observed in this assessment. In such situations, the larger grains on the bed will shield the smaller grains, preventing initiation of motion of most sediment until the larger particles start moving. Consequently, sediment transport estimates are usually based on the larger D_{84} particle grain size. Table 5 indicates whether the average D_{84} particles for the two data sets (2011 and 2012) are predicted to be mobile when water depth is at the observed top of low bank. For each site, the average D_{84} particle size is expected to be mobile at this flow depth according to the Rosgen curve for predicting particle size entrained by a given shear stress (Rosgen 2008), with the exception of site W1 (the most downstream monitoring reach on Wolf Run). This indicates that these substrates are unstable aquatic habitat, with the exception of W1. At W1 location the channel is wide, rather shallow and channel slope is lower. These conditions contribute to a rather low calculated shear stress when water depth is at the observed top of low bank. Additionally, the measured active riffle D_{84} was largest at site W1. The lower predicted shear coupled with the presence of larger substrate indicates the bed is stable in this reach.

Additional data obtained through the pebble count effort are summarized in Appendix B. Tables B1 and B2 (both within Appendix B) indicate the median particles observed in the pools and riffles, respectively, over the entire surveyed reach for both years. The median particle size observed in the pools should be smaller than the median particle size observed in the riffles. Riffles are by definition comprised of coarser material and pools are lower gradient regions were sediment deposition occurs. Overall, this is true for the measured data set. The pool substrate appears coarser than might be expected for a depositional feature, but for most of these impacted reaches true pools were not always observed. The pools monitored were often shallow, flat features instead of deep, scour features. Pool depth was often limited by channel incision to bedrock. The lack of true pools within the watershed indicates hydromodification has occurred, either due to channel incision to bedrock or because historically straightened reaches lack the pools associated with meander pattern.

F. Observations

In addition to photographs of the permanent cross-section locations, Appendix A also contains photographs of observations such as bank erosion areas/exposed banks, poor riparian protection, exposed tree roots, etc. The degraded conditions depicted in these images are typical for each monitoring reach.

IV. DISCUSSION & CONCLUSIONS

Although surveying indicated that many of the sites were relatively stable over the monitoring period, the assessment does indicate that hydromodification is causing bed and bank erosion, sedimentation, and habitat loss (low in-stream and riparian habitat). The condition of each reach will help define sustainability of various restoration or management projects and the compatibility of such projects with land use and channel management activities.

Significant stream disturbances noted through the field investigation of Wolf Run and its tributaries included:

- Minimal or absent riparian zone,
- Active bank erosion / absent bank vegetative protection,
- Floodplain encroachment and / or channel incision such that floodplain connection is reduced,
- Channel armoring,
- Unmitigated stormwater runoff from roads and other paved surfaces, and
- Channelization.

Disturbances were observed to some degree at all sites. These disturbances have initiated adjustments to channel dimensions (cross-section dimension, planform/pattern, and profile (slope)), such as channel incision and over-widening. The degree of such adjustments depends on the magnitude of the disturbances, the erosion resistance of the channel banks (cohesiveness) and substrates, the type and density of riparian vegetation, and the presence of grade controls. Within the study area there are several exposures of bedrock. Though the monitored reaches do exhibit channel incision, over widening, and reduced access to the floodplain in some locations, the relatively cohesive nature of the clay and silt material in the channel banks and the presence of bedrock in the stream beds, have resulted in the relatively stable condition (little observed active vertical and lateral stream adjustment) of these reaches over the monitoring period. Though rates of channel change may not currently be rapid, these reaches do not provide sufficient habitat for aquatic life.

A. Site Summaries

Below, observations and assessment data are summarized for each monitoring site. A visual summary of many of these observations is presented in Exhibit 2, page 20.

Map Document: (P:\Project_Files\Kentucky\KY10-030_LFUCG_WolfRun\Mapping\GIS\Exhibits\HydromodAssessment_Reaches_Ex2.mxd) 7/19/2012 -- 2:53:56 PM sje

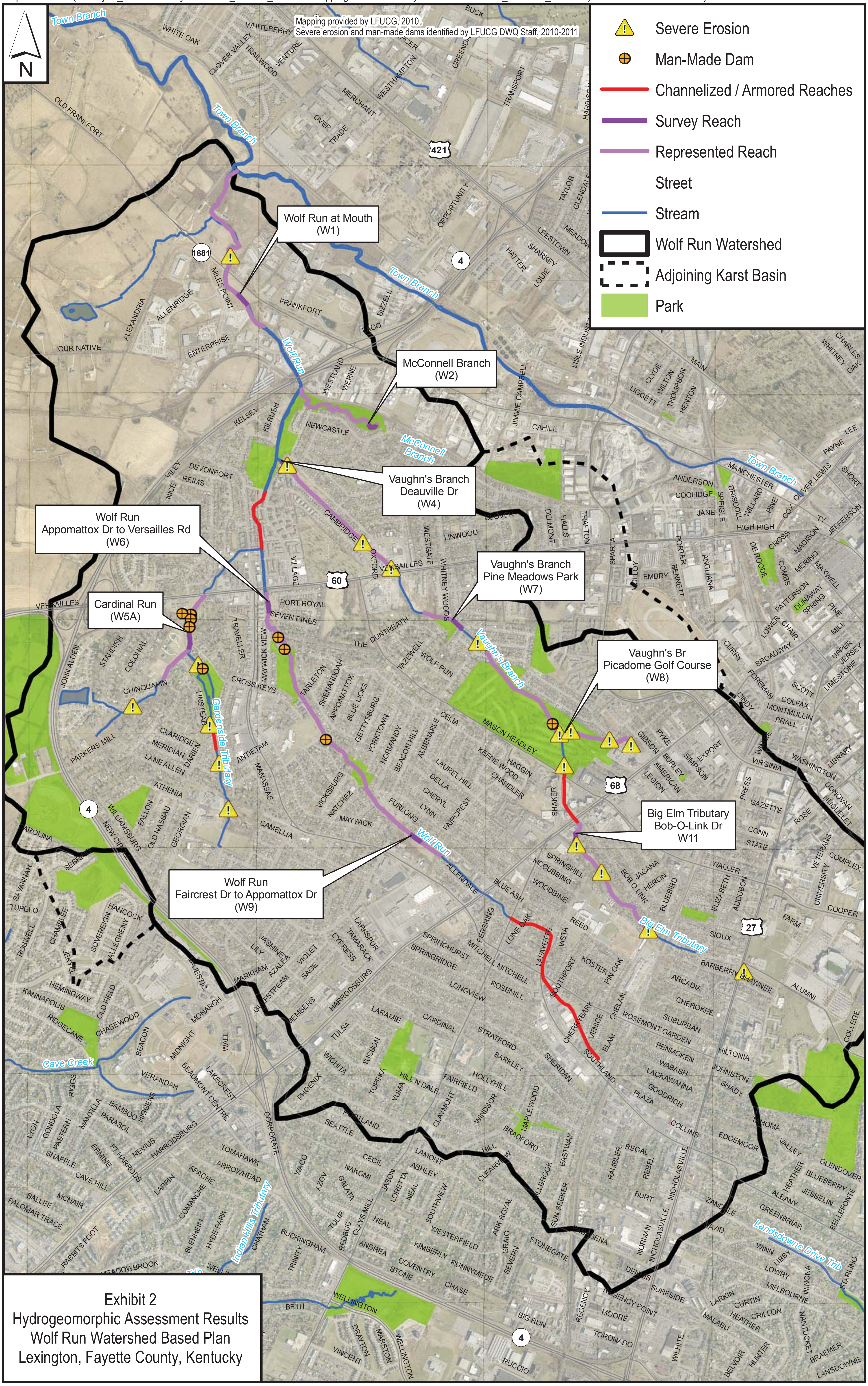


Exhibit 2
Hydrogeomorphic Assessment Results
Wolf Run Watershed Based Plan
Lexington, Fayette County, Kentucky

1. W1, Wolf Run, Old Frankfort Pike

This stream reach is approximately 3,735 feet upstream of the mouth of the Wolf Run watershed and is the most-downstream reach surveyed by this assessment. Thus, it is the largest stream channel surveyed in this assessment. Trash/debris (*i.e.,* shopping carts) was abundant in this reach. Areas of raw, nearly vertical, eroding stream banks were observed in this assessment (Exhibit 2 and Appendix A). The permanent cross-section survey shows some erosion at the toe of the slope on the left, descending bank. The stream has riparian cover on both sides for much of this reach, but there are still segments where riparian cover is absent. Additional area is available to expand the riparian width and/or enhance the composition of the existing riparian buffer. Habitat assessment data indicate there are a relative stable mix of epifaunal substrate and a frequent occurrence of riffles, though the reach ranks as marginal for embeddedness and sediment deposition. For this site, the average D_{84} particle size measured in the active riffle is larger than for other sites, and is not expected to be mobile at the top of low bank flow depth. This indicates that these substrates provide stable aquatic habitat. But, this reach does have some bedrock-dominated pools and a rather monotonous bed comprised of run/shallow pool habitat based on the longitudinal profile survey.

Due to the existing undeveloped area adjacent to this reach, there is potential to improve the stream cross-section and profile (possibly through the installation of in-stream structures) to increase sediment transport, reduce bank erosion, and improve the physical aquatic habitat.

2. W2, McConnell Branch, Preston's Cave

McConnell Branch (W2), which receives most of its flow from Preston's Cave and the upstream McConnell Springs groundwater sources, exhibits modulated hydrology due to the karst drainage. Banks within this reach are relatively stable and not actively eroding. In fact, in-stream deposition and aggradation seem to be more negatively impacting aquatic habitat than erosion. The stream is likely over-widened and thus does not have the capacity to transport the current sediment load. Though this reach is shaded by riparian vegetation, algal growth was observed throughout the reach during 2012 monitoring. Additionally, the riparian vegetation contains non-desirable, invasive species and the riparian zone would benefit from invasive species removal/management and establishment of site-specific, native vegetation. Stakeholders indicate that the observed sedimentation at this site may be a result of prior disturbance and fill rather than ongoing sediment transport to the reach. Additional study and design calculations could be used to evaluate what the current sediment load to this stream is (though complicated by the karst drainage) and whether modifications to the channel dimensions and profile could increase sediment transport capacity of the stream in order to alleviate the embedded substrate and sedimentation observed here. This reach has more pattern and more desirable vertical diversity of the streambed, with rather deep pools being measured by the longitudinal profile survey. This reach is an attractive recreational segment accessed by the public on an adjacent trail. Improving the riparian vegetation and sediment transport/aquatic habitat would improve this stream as a recreational resource as well as improve stream function/aquatic habitat. Several tributaries enter McConnell Branch within the reach represented by this station. Their condition needs to be further evalutated if this reach is prioritized for remediation activities. There is stakeholder concern about headcutting within a tributary that enters McConnell Branch downstream of the surveyed reach. Unstable tributaries could be contributing high sediment load to McConnell Branch.

3. W4, Vaughn's Branch, Valley Park

The reach represented by this site is the most downstream portion of Vaughn's Branch, just upstream of its confluence with Wolf Run. As observed during the longitudinal profile survey and as indicated by the habitat assessment data, there is a relatively frequent occurrence of riffles in this section of stream, which provides aquatic habitat, but visible bank erosion, lack of bank cover, and low riparian width reduce the stability and quality of this reach. Exhibit 2, page 20, shows the location of a severe erosion area near the confluence with Wolf Run. The longitudinal profile indicated a deep pool on bedrock and the remainder of the reach was predominately riffle and run habitat. The vertical diversity could be enhance to create more niche habitats for aquatic life. Photos (Appendix A) show the impacts erosion has had to infrastructure (utility pole, stormwater outfall) Improvement to this section of Vaughn's Branch could focus more on creating a stable stream cross-section, which would stabilize the stream banks, and increasing riparian width and quality. The public frequently crosses Vaughn's Branch in the downstream portion of this surveyed reach. This contributes to frequent trash dumping within this reach. If the water quality and physical stream condition were improved, it would be a good location to re-connect the public with their water resources.

4. W5A, Cardinal Run, Parkers Mill Road

This reach, on private property, has tremendous potential for restoration and achieving substantial ecological lift. The in-stream habitat is very low, due to low availability of stable substrate, embeddedness of substrate, and some in-stream deposition. The substrate data collected during this assessment indicate the presence of much finer bed material (silt/clay conglomerate) in this reach of Cardinal Run compared to every other site where the beds are dominated by gravel and small cobble. The bed substrate at this site does not provide adequate aquatic habitat (i.e. lack of gravel and cobble for macroinvertebrate colonization) and could be enhanced through restoration activities. The profile observed for Cardinal Run Tributary (W5A) indicates that the pool from approximately station 290 to 310 filled in roughly three inches due to deposition. This material was likely supplied by the deepening of the pool at station 16. The biggest and most obvious need for this reach is bank stabilization/vegetation and riparian planting. The riparian zone is highly modified by mowing activities and removal of all streamside, rootwad-producing vegetation. Bare and vertical banks, susceptible to erosion, were observed in this reach. There is a wetland area adjacent to the stream reach, as well as a wetland area downstream of the assessment reach. Several mallard ducks were observed in the wetland zones during 2011 data collection. These wetland features could be incorporated into the overall restoration of the site, providing additional water quality and aquatic habitat improvements.

5. W6, Wolf Run, Wolf Run Park

Habitat assessment data indicates that available epifaunal substrate and cover are diminished in this reach, but like most of the sites, the lack of bank protection and stability and riparian vegetation most contribute to this streams poor aquatic quality. Due to its location adjacent to Wolf Run Park, restoration of stream dimension, pattern, profile, and riparian zone is feasible in this reach. Though the habitat assessment indicates a relatively frequent occurrence of riffles, the longitudinal profile surveyed in this assessment indicates long stretches of run/shallow pool habitat. This reduced diversity in the stream profile indicates reduced habitat to support aquatic species. The assessment observed exposed bedrock within this reach, which also contributes to the lack of vertical profile diversity. This watershed is highly karst, thus prior to any stream restoration, especially bedrock excavation, additional analyses need to be completed to ensure that excavation would not result in a sinking stream. The presence of bedrock can be problematic from a restoration potential, but deep pools can be excavated within bedrock if necessary and stream structures can be utilized with caution. If the stream can be partially relocated to the area within Wolf Run Park, extensive bedrock could possibly be avoided. If the water quality and physical stream condition were improved, this reach would be a good location to re-connect the public with their water resources.

6. W7, Vaughn's Branch, Pine Meadow Park

This reach has a strikingly low habitat assessment score, with very low availability of stable substrate, high indication of substrate embeddedness and in-stream deposition, evidence of eroding banks and little bank protection, and diminished riparian zone. Changes in the longitudinal profile observed in the second monitoring event indicate the mobility of substrates within this reach. There has been some bank stabilization by LFUCG within small portions of the surveyed reach. The downstream extent of this surveyed reach contains a sanitary sewer crossing; the pipe was exposed during 2011 monitoring and was subsequently replaced and protected by armoring. The larger section of Vaughn's Branch, of which this site is representative, contains numerous stormwater sewer outfalls, as well as sanitary sewer crossings. This complicates restoration, but stream improvements can be made while considering these constraints. Opportunities may exist to incorporate BMPs for mitigating stormwater adjacent to this reach. Due to its location adjacent to Pine Meadow Park, restoration of stream dimension, profile, and riparian zone is feasible in this reach. To a lesser degree, stream pattern could be improved within this reach. If the water quality and physical stream condition were improved, it would be a good location to re-connect the public with their water resources.

7. W8, Vaughn's Branch, Picadome Golf Course

This reach, within Picadome Golf Course, also has a strikingly low habitat assessment score, with very low availability of stable substrate, high indication of substrate embeddedness and in-stream deposition, evidence of eroding banks and little bank protection, and a riparian corridor highly modified by landscape maintenance activities and removal of all streamside, rootwad-producing vegetation. Photos (Appendix A) and Exhibit 2 show areas of severe erosion. Due to its location within LFUCG Park's property, restoration of stream dimension, pattern, profile, and riparian zone is feasible in this reach if changes to the golf course are acceptable. This is a very public location to showcase a successful stream restoration project and re-connect the public with their water resources.

As indicated in Exhibit 2, Big Elm tributary contributes flow to Vaughn's Branch within the golf course. There is not a channelized connection. The Big Elm tributary flows into a large sinkhole area. When the sinkhole fills, floodwater flows across the fairways to Vaughn's branch. The absence of a channel connection from Big Elm tributary to Vaughn's Branch causes erosion. This could be remedied by restoration of the channel, though it will impact play at the golf course and require careful planning.

8. W9, Wolf Run, Faircrest Drive

The habitat assessment of this reach indicates poor habitat, but the scores for this reach are not as low as for many of Wolf Run's streams. The reach was characterized as having an acceptable frequency of riffles, and this assessment surveyed three consecutive riffles that were observed to have relatively un-embedded substrate. However, the presence of rather long stretches of monotonous, shallow run/shallow pool habitat was also observed. This is likely indicative of the channel alteration/channelization at this site, which is denoted in the habitat assessment and is visible on Exhibit 1. This stream is rather wide and shallow, which diminishes flow depth during dry periods and can stress aquatic species. Substrate data indicate the bed is comprised of gravel and small cobble, with the pools containing smaller sized material. Channelization of this reach is obvious and the stream would benefit from re-establishment of a meandering pattern. Due to its location adjacent to the Allendale Greenway, restoration of stream dimension, pattern, profile, and riparian zone is feasible in this reach. Some riparian plantings have been installed within the greenway area, but the small saplings have been killed by recent dry conditions (summer 2012).

9. W11, Big Elm Tributary, Harrodsburg Road

As observed during the longitudinal profile survey and as indicated by the habitat assessment data, there is a relatively frequent occurrence of riffles in this section of tributary, which provides aquatic habitat. Photos (Appendix A) show an area where concrete armors the bank and Exhibit 2 shows areas of severe erosion. Sediment deposition and embeddedness are suboptimal in this reach, but still indicate better habitat than many other reaches evaluated. Improvement to Big Elm tributary could focus more on stabilizing the stream banks, removing concrete bank armor, and increasing riparian width and quality.

B. Remediation Opportunities

Opportunities for improvement were observed for each reach surveyed and are indicated for each site above. Based on the lack of obvious physical constraints in a reach, position in the landscape, etc., sites W5A, W6, W7, W8, and W9 are considered the highest priority for restoration or enhancement. The data collected in this assessment can be used by watershed stakeholders to inform future restoration and management strategies along the assessed reaches.

Recommended measures include restoring floodplain access; restoring channel dimensions, pattern, and profile in previously channelized segments; providing bank stabilization where opportunity for restoring channel dimensions is limited; and increasing riparian width and vegetation quality throughout the watershed. Additional remediation measures to consider, though specific locations for application were not identified in the assessment, include replacing crossing structures with less constricting bridges and culverts and mitigating stormwater runoff. The Wolf Run Watershed is highly developed with a high percentage of impervious surfaces. Reducing and treating stormwater runoff throughout the entire watershed can mitigate erosive flows, reduce pollutants, and promote conditions for improved aquatic habitat in Wolf Run and its tributaries. Specific analysis of the impacts of flow alterations at each site should be performed to determine which remediation measures are best suited to reduce and treat stormwater for a particular site. Additionally, eliminating future channel and riparian manipulations should be a goal across the entire watershed.

Based on review of the *Habitat and Macroinvertebrate Assessment Report* (Olson 2011), habitat assessments indicated that riparian zone width was routinely the lowest overall habitat score parameter, indicating that remediation activities focusing on expanding the width of the vegetated area beside the stream will provide the greatest benefit throughout the watershed. Low habitat scores for epifaunal substrate / available cover, embeddedness, and velocity depth regime together suggest that little habitat is available for macroinvertebrates due to an lack of pools and available cobble habitat in the stream. Restoration activities focused on creating pools, increasing base flows, and increasing the in-stream habitat will aid in improving the macroinvertebrate community within the watershed.

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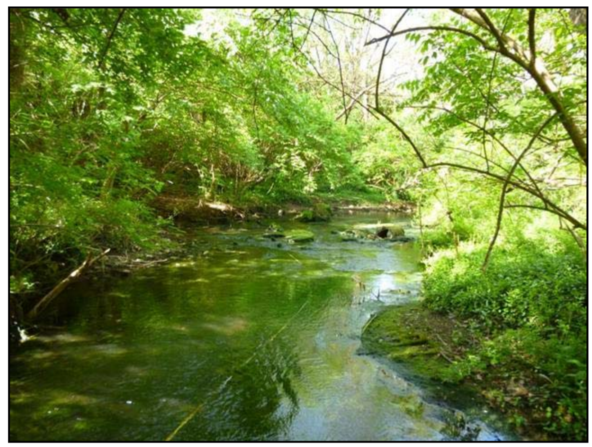
APPENDICES

APPENDIX A – PHOTO LOG

W1, 2011 Upstream View of Permanent Cross-section

W1, 2012, Upstream View of Permanent Cross-section

W2, 2011, Downstream View of Permanent Cross-section



W2, 2012, Downstream View of Permanent Cross-section

W4, 2011, Downstream View of Permanent Cross-section

W4, 2012, Downstream View of Permanent Cross-section

W5A, 2011, Downstream View of Permanent Cross-section

W5A, 2012, Downstream View of Permanent Cross-section

W6, 2011, Downstream View of Permanent Cross-section

W6, 2012, Downstream View of Permanent Cross-section

W7, 2011, Upstream View of Permanent Cross-section

W7, 2012, Upstream View of Permanent Cross-section

W8, 2011, Upstream View of Permanent Cross-section

W8, 2012, Upstream View of Permanent Cross-section

W9, 2011, Upstream View of Permanent Cross-section

W9, 2012, Upstream View of Permanent Cross-section

W11, 2011, Downstream View of Permanent Cross-section

W11, 2012, Downstream View of Permanent Cross section

W1, 2011, Left Bank Erosion Area within Surveyed Reach

W1, 2012, Section Where Bank Stabilization And Riparian Enhancement Would Be Beneficial

W2, 2012, Significant Amounts of Algae Observed throughout Surveyed Reach

W2, 2012, Riparian Canopy, But Contains A Significant Invasive Species; Algae And Sedimentation Reduce Aquatic Habitat

W4, 2011, Erosion Around Stormwater Infrastructure

W4, 2011, Poor Quality Vegetation in Riparian Zone and Bank Erosion

W4, 2012, Left Bank Erosion within Surveyed Reach; Exposed Tree Roots

W4, 2011, Bank Completely Eroded Around Utility Pole, Was Replaced Following This Assessment

W4, 2012, Bedrock Within Upstream Portion Of Surveyed Reach, Creates Stable Bed But Reduces Aquatic Habitat

W5A, 2011, Rather Straight Channel without Riparian Buffer within Residential Area

W5A, 2011, Wetland And Lawn Areas Adjacent To Surveyed Reach

W5A, 2012, Raw Eroding Areas Due To Lack Of Cover By Vegetation

W6, 2011, Embedded Substrate; Little Vertical Streambed Diversity

W6, 2011, Typical Unvegetated Bank

W6, 2012, Riparian Area Could be Expanded within Wolf Run Park

W7, 2011, Exposed Infrastructure

W7, 2011, Instream Deposition within Degraded Stream Channel

W7, 2012, Poor Riparian Zone; Little Vertical Streambed Diversity

W8, 2011, Bank Erosion and No Riparian Buffer

W8, 2011, Poor Instream Habitat, Bank Erosion, And No Riparian Buffer

W9, 2011, Poor Quality Riparian Zone Offering Little Bank Protection

W9, 2012, Available Area Along Left Bank for Additional Riparian Zone Expansion

W9, 2012, Downed Tree Across Stream May Lead to Additional Channel Degradation

W11, 2011, Low Quality Riparian Vegetation

W11, 2011, Concrete Armoring Within Surveyed Reach

W11, 2011, Relatively Stable Channel

Wolf Run, Concrete Channel Contained Within Southland Drive; Not Characterized By Study

Wolf Run, Concrete And Rock Channel Contained Within Street At Rosemont Garden; Not Characterized By Study

APPENDIX B – ADDITIONAL PEBBLE COUNT DATA

Table B1. Median particle size calculated from reach-wide pool pebble count

Site Name	Stream, Location	2011 Reach-Wide Pool D50, mm (Median Particle Size)	2011 Particle Size Description	2012 Reach-Wide Pool D50, mm (Median Particle Size)	2012 Particle Size Description
W1	Wolf Run, Old Frankfort Pike	18.1	Coarse Gravel	19.3	Coarse Gravel
W2	McConnel Branch, Prestons Cave	0.06	Silt / Clay	0.22	Silt / Clay
W4	Vaughn's Branch, Valley Park	bedrock	bedrock	bedrock	bedrock
W5A	Cardinal Run, Parkers Mill Road	0.04	Silt / Clay	12.9	Medium Gravel
W6	Wolf Run, Wolf Run Park	3.0	Very Fine Gravel	10	Medium Gravel
W7	Vaughn's Branch, Pine Meadow Park	*		*	
W8	Vaughn's Branch, Picadome Golf Course	9.5	Medium Gravel	6	Fine Gravel
W9	Wolf Run, Faircrest Drive	19.3	Coarse Gravel	17.6	Coarse Gravel
W11	Big Elm Tributary, Harrodsburg Road	19.3	Coarse Gravel	22	Coarse Gravel

*W7 profile did not have distinct riffle and pool substrate; see pebble count data listed in reach-wide riffle table

Table B2. Median particle size calculated from reach-wide riffle pebble count

Site Name	Stream, Location	2011 Reach-Wide Riffle D50, mm (Median Particle Size)	2011 Particle Size Description	2012 Reach-Wide Riffle D50, mm (Median Particle Size)	2012 Particle Size Description
W1	Wolf Run, Old Frankfort Pike	32.0	Coarse Gravel	13.4	Medium Gravel
W2	McConnel Branch, Prestons Cave	10.8	Medium Gravel	12.8	Medium Gravel
W4	Vaughn's Branch, Valley Park	52.4	Very Coarse Gravel	24.8	Coarse Gravel
W5A	Cardinal Run, Parkers Mill Road	0.04	Silt / Clay	12.5	Medium Gravel
W6	Wolf Run, Wolf Run Park	16.5	Coarse Gravel	25.1	Coarse Gravel
W7	Vaughn's Branch, Pine Meadow Park	7.2*	Fine Gravel	37.7*	Very Coarse Gravel
W8	Vaughn's Branch, Picadome Golf Course	18.1	Coarse Gravel	6.3	Fine Gravel
W9	Wolf Run, Faircrest Drive	34.2	Very Coarse Gravel	29.1	Coarse Gravel
W11	Big Elm Tributary, Harrodsburg Road	25.9	Coarse Gravel	19.9	Coarse Gravel

*W7 profile did not have distinct riffles and pool substrate; this pebble count represents the entire surveyed reach

Figure B1. W1 - 2011 Particle size distributions for reach-wide pebble counts

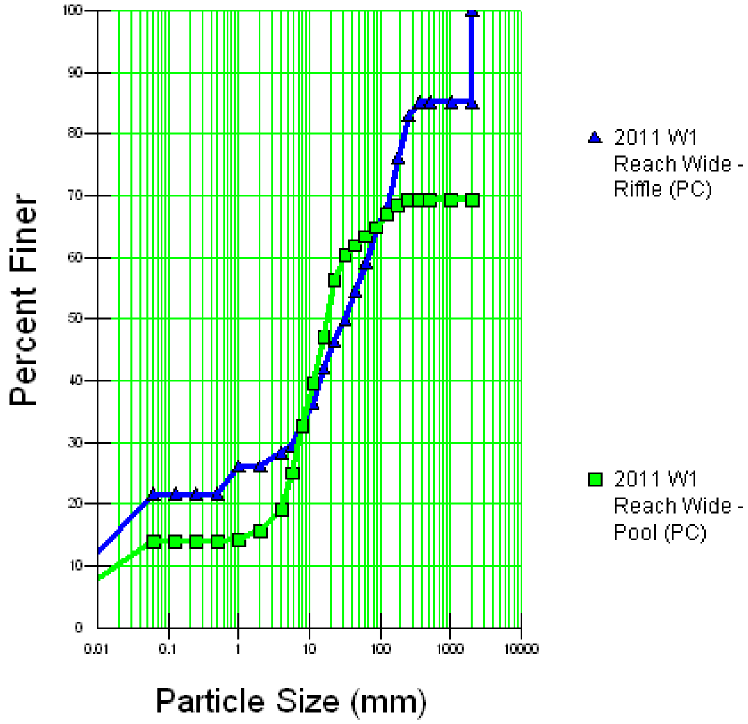


Figure B2. W1 - 2012 Particle size distributions for reach-wide pebble counts

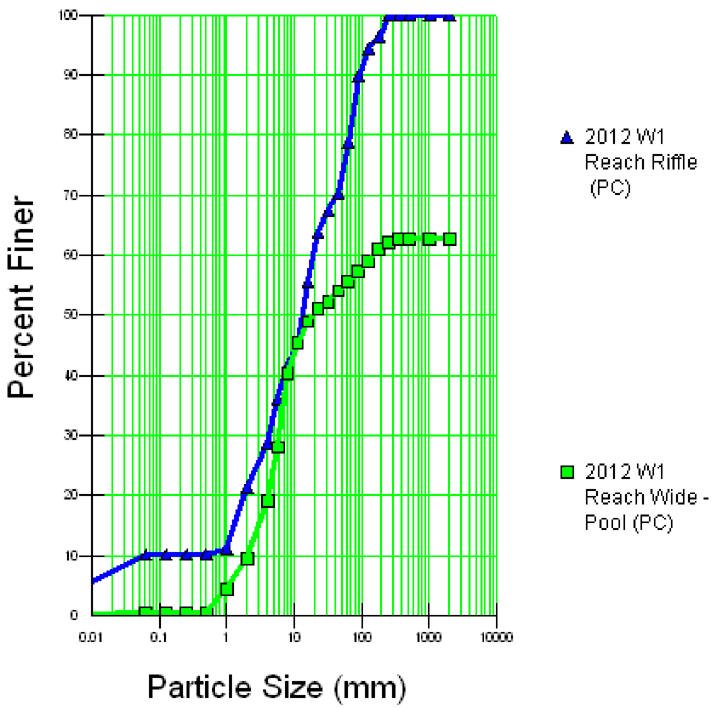


Figure B3. W2 - 2011 Particle size distributions for reach-wide pebble counts

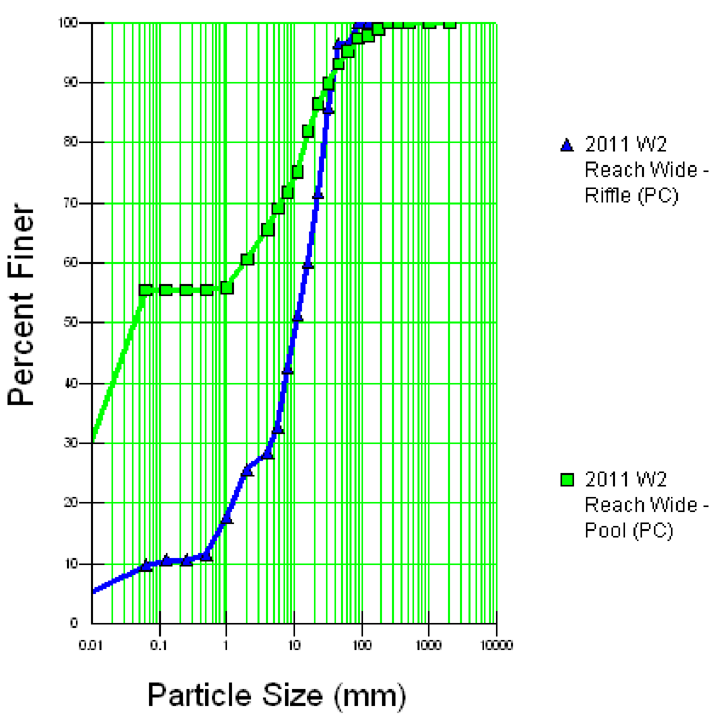


Figure B4. W2 - 2012 Particle size distributions for reach-wide pebble counts

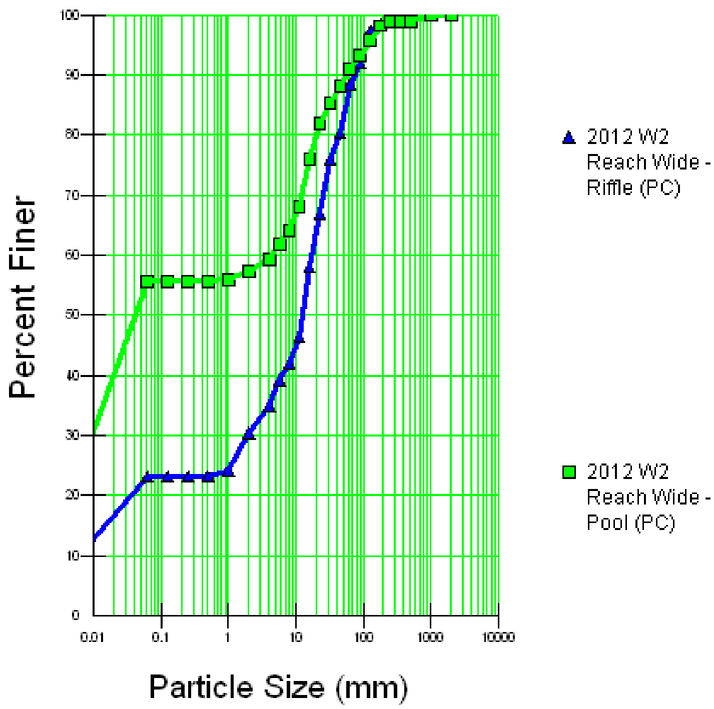


Figure B5. W4 - 2011 Particle size distributions for reach-wide pebble counts

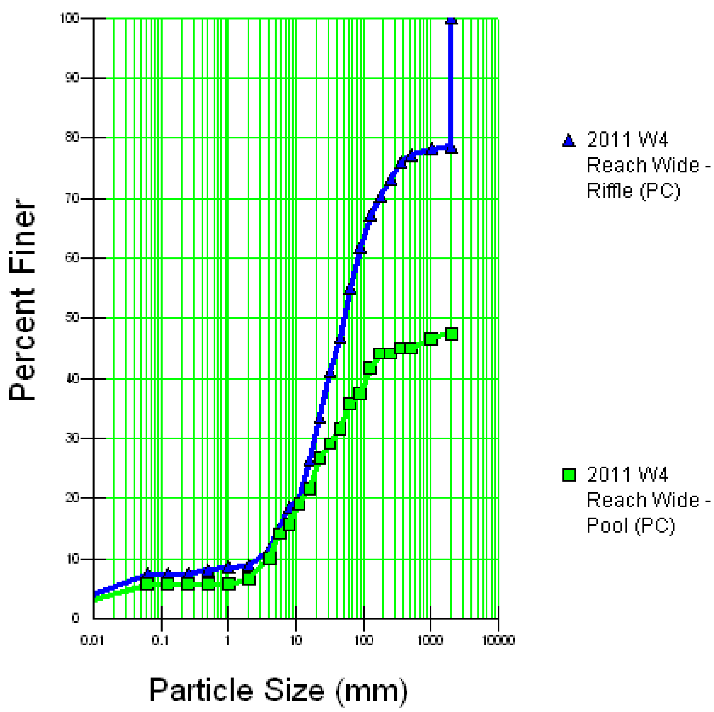


Figure B6. W4 - 2012 Particle size distributions for reach-wide pebble counts

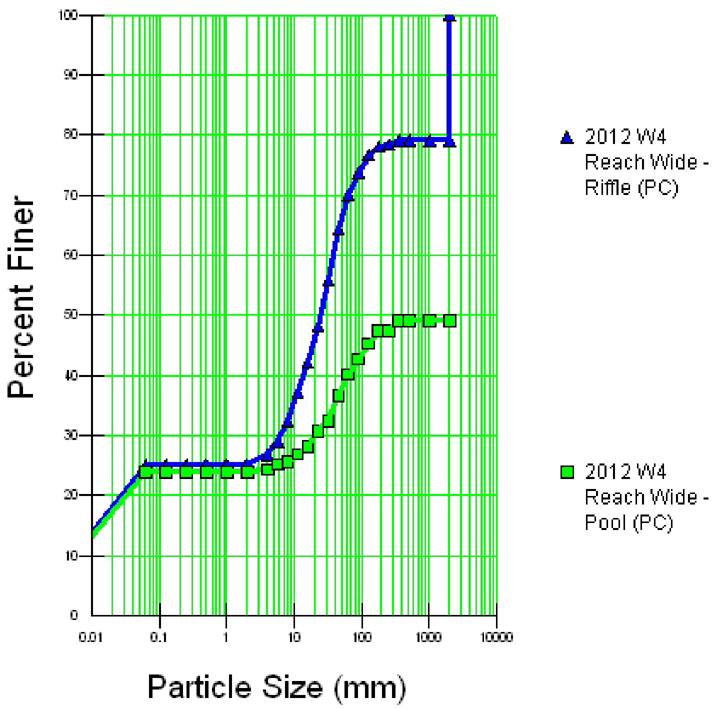


Figure B7. W5A - 2011 Particle size distributions for reach-wide pebble counts

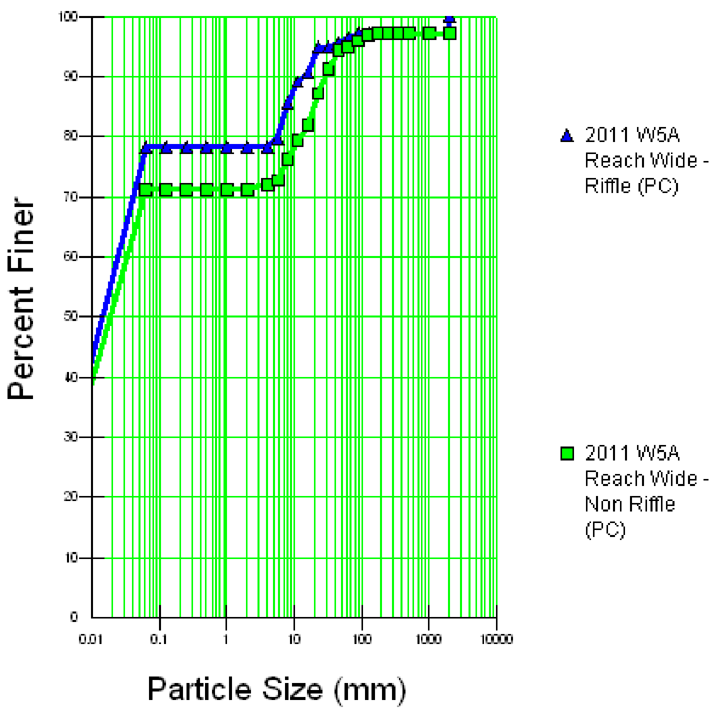


Figure B8. W5A - 2012 Particle size distributions for reach-wide pebble counts

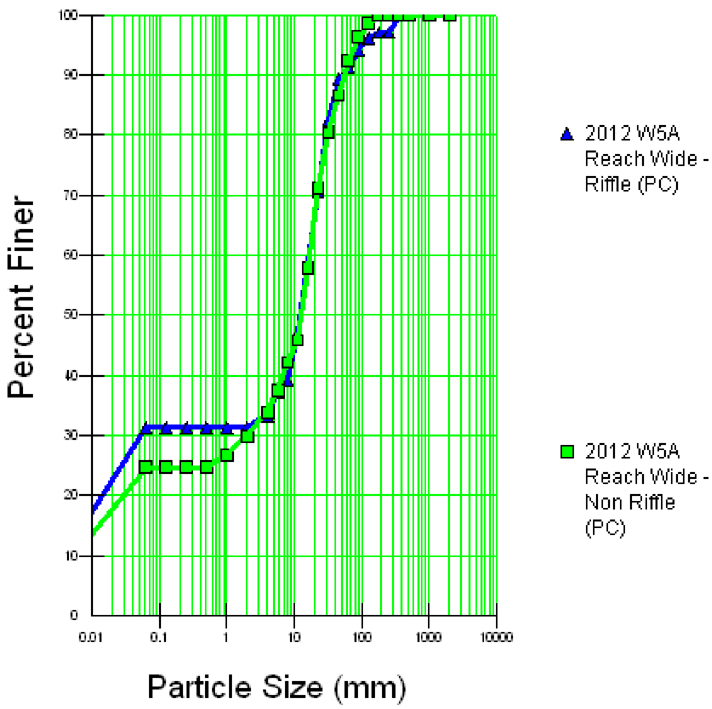


Figure B9. W6 - 2011 Particle size distributions for reach-wide pebble counts

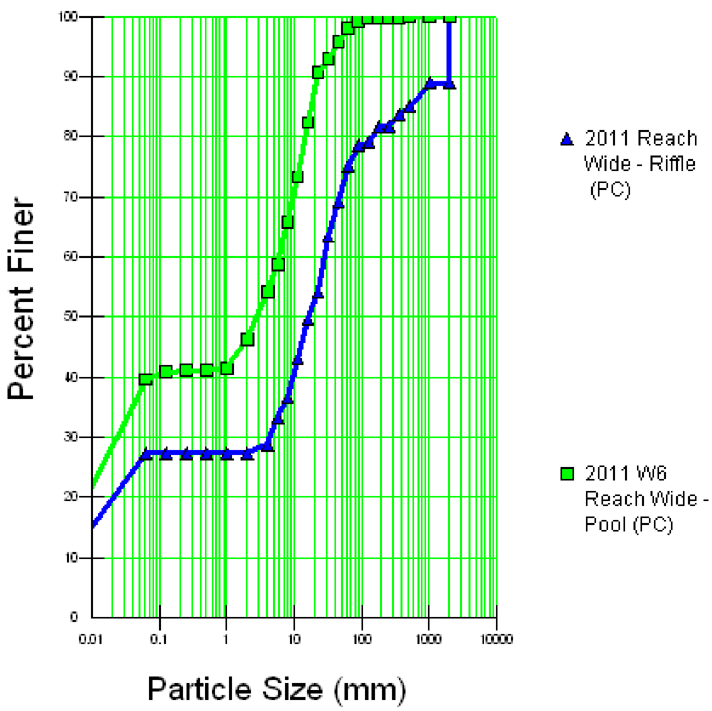


Figure B10. W6 - 2012 Particle size distributions for reach-wide pebble counts

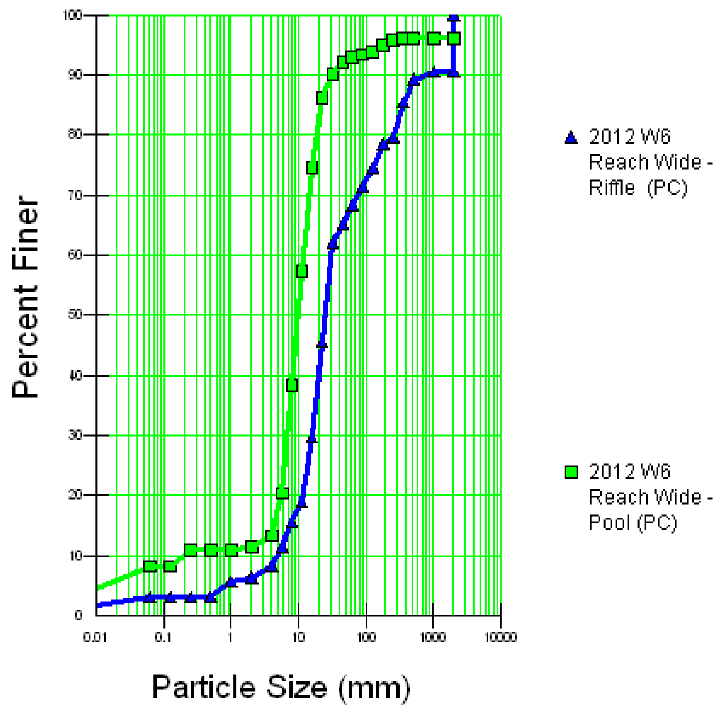


Figure B11. W7 – 2011 and 2012 Particle size distributions for reach-wide pebble counts

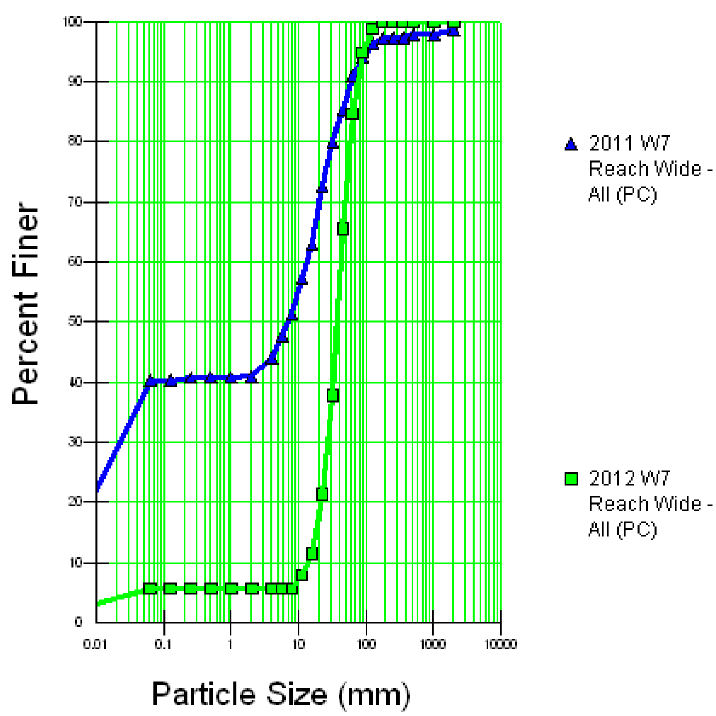


Figure B12. W8 – 2011 Particle size distributions for reach-wide pebble counts

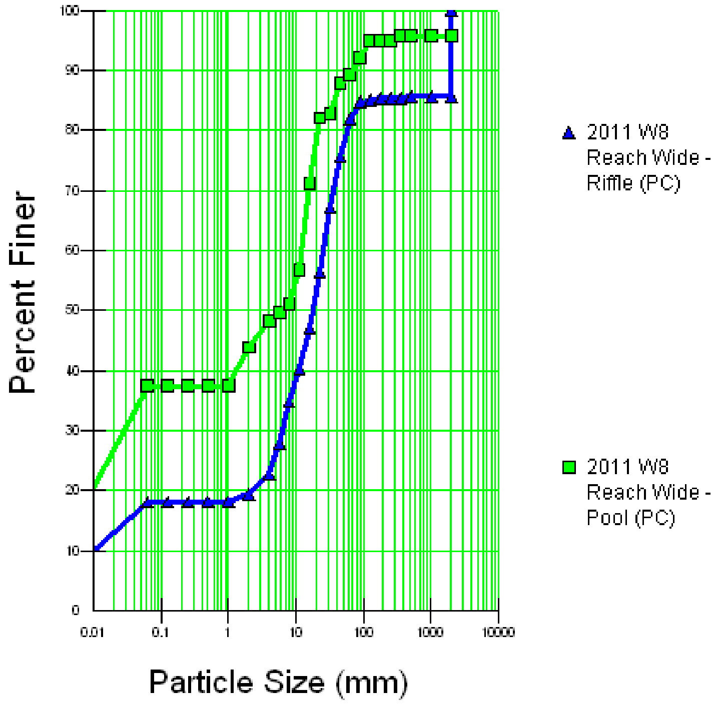


Figure B13. W8 – 2012 Particle size distributions for reach-wide pebble counts

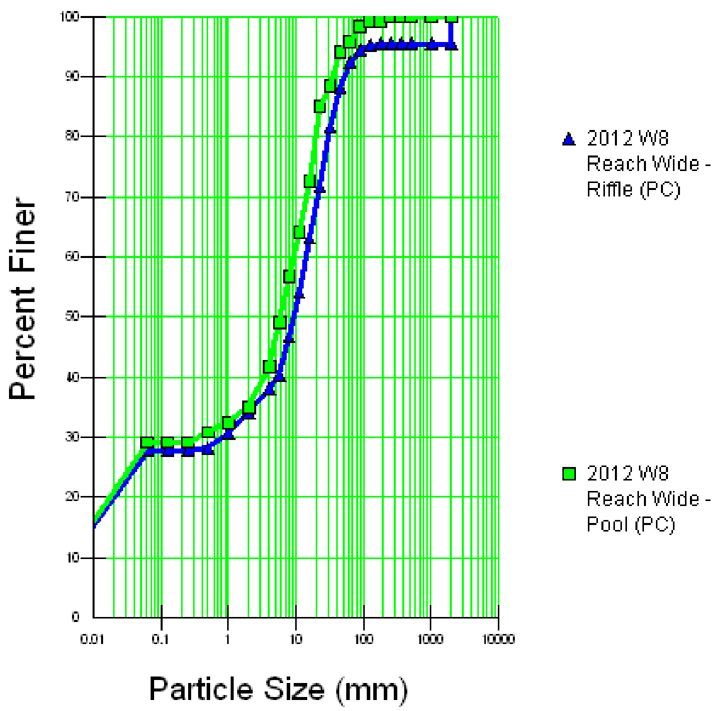


Figure B14. W9 – 2011 Particle size distributions for reach-wide pebble counts

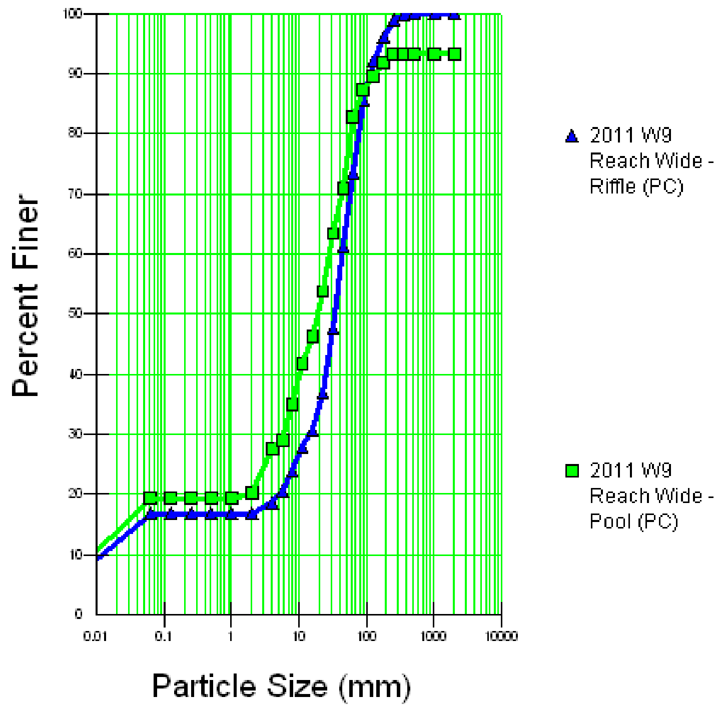


Figure B15. W9 – 2012 Particle size distributions for reach-wide pebble counts

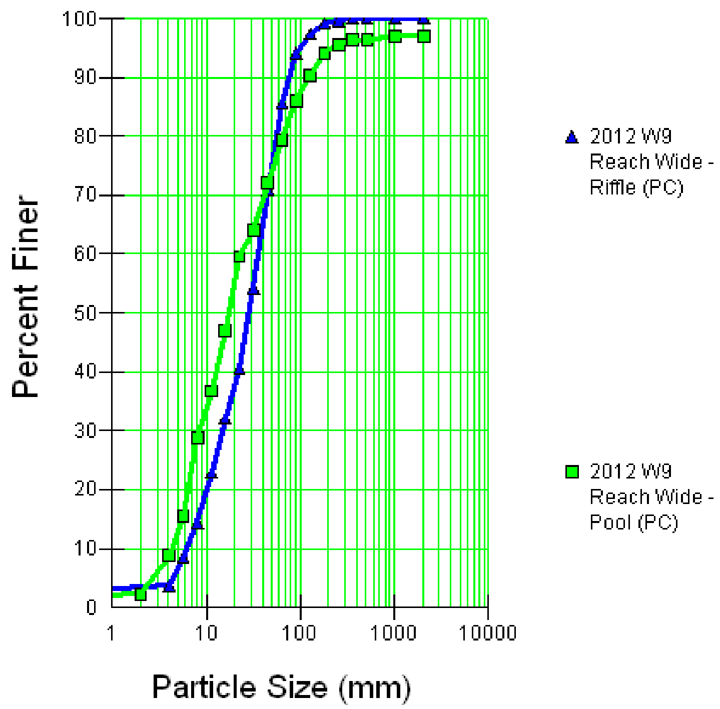


Figure B16. W11 – 2011 Particle size distributions for reach-wide pebble counts

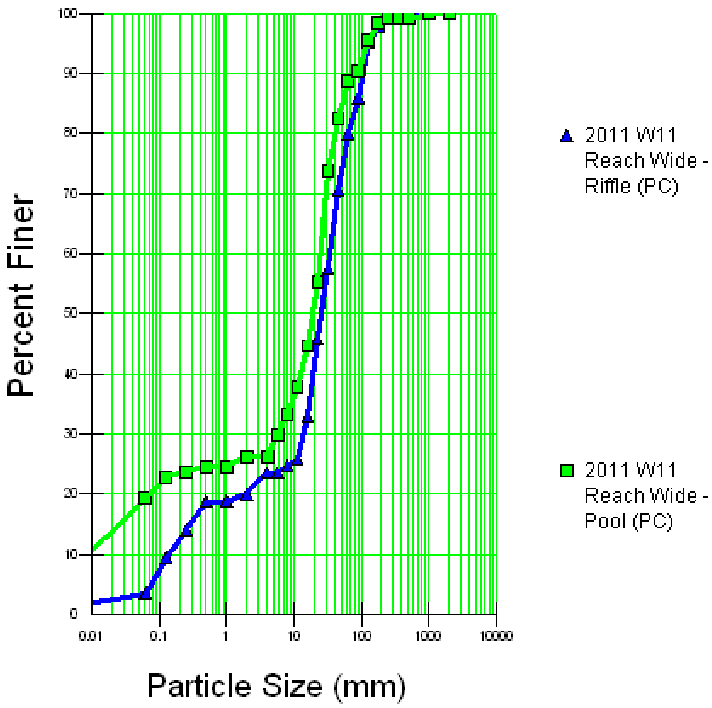


Figure B17. W11 – 2012 Particle size distributions for reach-wide pebble counts