CHAPTER IV. ANALYSIS

A. Aquatic Community and Habitat

1. Fish

Although not collected under this project, fish have been sampled using KDOW methods from 2003 to 2011 at the mouth of the watershed under annual LFUCG MS4 permit monitoring. Over that time period, 22 species of fish have been collected from Wolf Run but only 12 to 15 species are typically collected in an individual year. Species collected in multiple sampling years include stoneroller *(Campostoma anomalum*), scarletfin shiner *(Lythrurus fasciolaris*), bluntnose minnow (*Pimephales notatus*), fathead minnow *(P. promelas*), blacknose dace *(Rhinichthys atratulus*), creek chub *(Semotilus atromaculatus*), white sucker *(Catostomus commersoni*), northern hogsucker *(Hypentelium nigricans*), yellow bullhead*(Ameiurus natalis*), mosquitofish *(Gambusia affinis*), banded sculpin*(Cottus carolinae*), green sunfish (*Lepomis cyanellus*), bluegill *(L. macrochirus*), longear sunfish *(L. megalotis*), greenside darter *(Etheostoma blennoides*), fantail darter *(E. flabellare*), and orangethroat darter *(E. spectabile*). Species that have only been collected during one or two sampling years include: carp *(Cyprinus carpio*), rosyface shiner *(Notropis rubellus*), black bullhead *(Ameiurus melas*), warmouth *(L. gulosus*), and spotted bass *(M. punctulatus*). Index of Biotic Integrity (IBI) ratings have ranged from “excellent” to “fair,” although most years have been excellent.

2. Macroinvertebrates

Results of the macroinvertebrate sampling for the project are shown in Exhibit 26, page IV-2. Macroinvertebrate Bioassessment Index (MBI) scores calculated for the seven sampling stations in the Wolf Run Watershed resulted in classifications of “poor” at six sites. The other site, W12, was “very poor,” scoring just below the threshold of 19 for a “poor” rating. The minimum MBI score for a “fair” rating is 41 for wadeable streams, such as W1, and 39 for headwater locations in the Bluegrass Bioregion. This indicates that considerable improvement will be necessary to achieve a “fair” rating.

The low MBI scores observed in the Wolf Run watershed are the result of several conditions, most of which are re-occurring at each of the seven sampling stations. All stations were extremely low in the number of pollution intolerant EPT (ephemeroptera, plecoptera, and trichoptera commonly known as mayflies, stoneflies, and caddisflies) taxa. No station had more than two genera of EPT (W11 and W12 had zero genera) and % EPT ranged from 0 to 0.9 percent. With the exception of W5A, all stations were also relatively low in overall genus taxa richness, which ranged from eight to 14 taxa. The exception, W5A, had 30 total taxa. However, the higher taxa richness observed at this station was primarily the result of an increase in diversity of pollution tolerant taxa such as Chironomidae and annelida (midges and worms), as well as several tolerant members of mollusca. 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. The pollution tolerant isopod, *Lirceus fontinalis*, and the tolerant *Cricotopus/Orthocladius* members of Chironomidae were the most abundant organisms. The Habitat and Macroinvertebrate Report in Appendix D contains additional information.

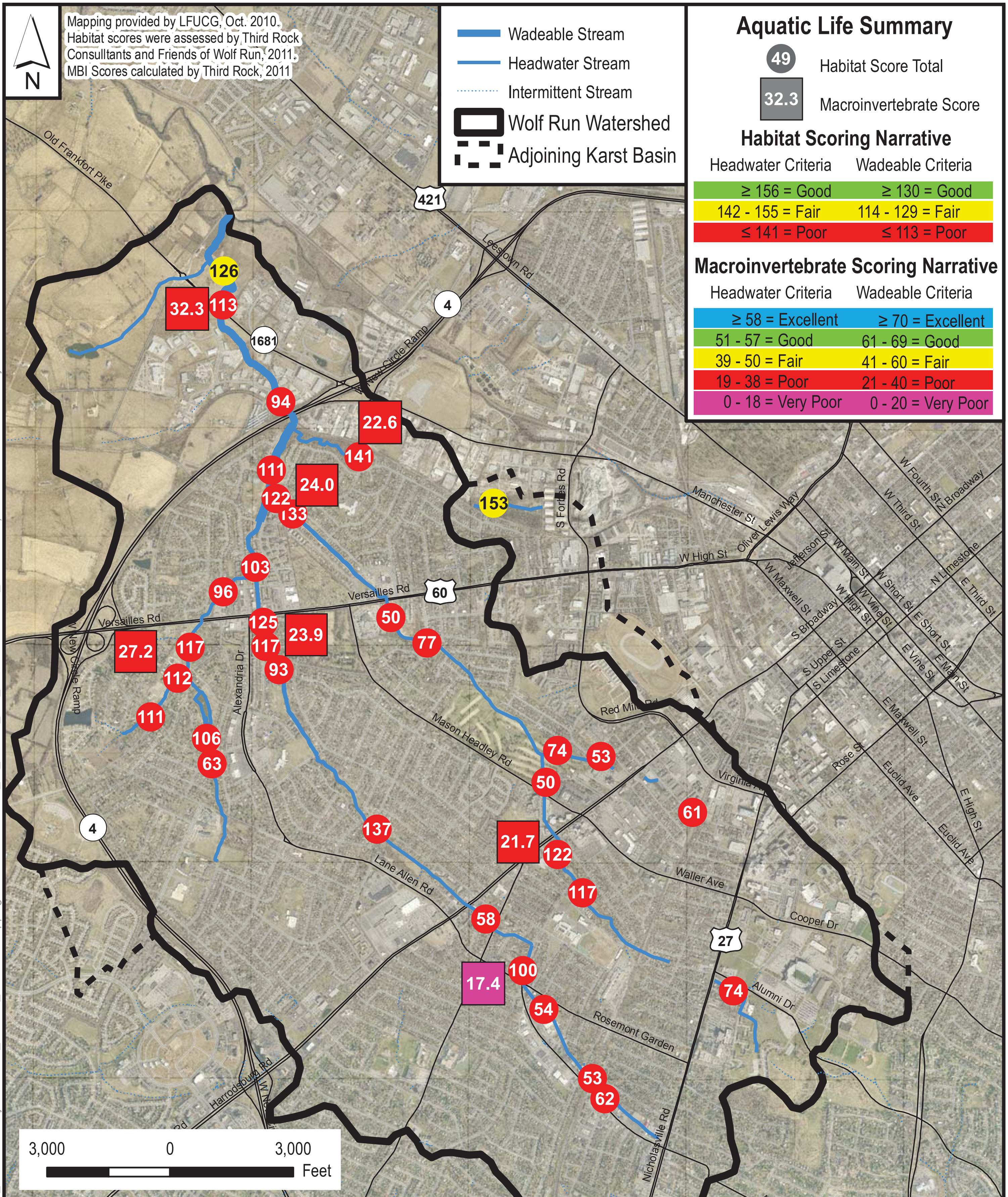

Exhibit 26
Habitat and Macroinvertebrate Scores
Wolf Run Watershed Based Plan
Lexington, Fayette County, Kentucky

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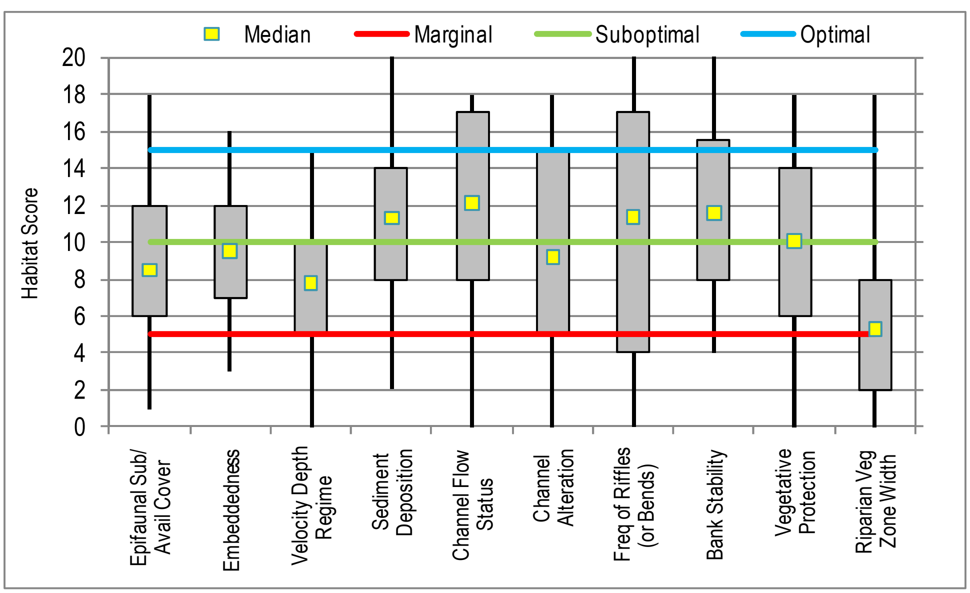
3. Habitat

Results of the habitat assessments for the project are shown in Exhibit 26, page IV-2. Total habitat scores ranged from 50 to 153. Out of the 33 reaches assessed, only two were "fair" with all others "poor." The "fair" scores were assessed within McConnell Springs Park (2A) and at the mouth of Wolf Run (1A1). Downstream of Preston's Cave (2B), scores were at the threshold between "fair" and "poor" with marginal sediment deposition and embeddedness scores causing the poor rating at that location. Wolf Run at the Furlong Drive Greenway (1F), where the riparian width is wider, also approaches a "fair" rating.

The lowest scores (50) were assessed at Vaughn's Branch at Pine Meadow Park (3C1) and at Big Elm Tributary on the Picadome Golf Course flowing into the sinkhole (4A). Each of these streams has poor scores across all parameters. Other extremely low sites are located in the headwaters of Wolf Run (1G1, 1H, 1J) and Vaughn's Branch (3E, 3F).

Figure 4 shows the range of scores for each habitat parameter measured under this project. As shown, several factors contributed to the poor habitat scores in the watershed. The riparian zone width was routinely the lowest overall 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 scores for epifaunal substrate/available cover, embeddedness, and velocity depth regime together suggest that little habitat is available for macroinvertebrates due to a 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. See Appendix D for additional information.

FIGURE 4 – WOLF RUN WATERSHED HABITAT SUMMARY



4. Hydrogeomorphic Assessment

Nine hydrogeomorphic stream reaches were surveyed twice. Surveying was initially conducted from May 23 to June 22, 2011 and again from March 13 to May 17, 2012 after numerous erosive flow events had occurred. Appendix E contains the full *Hydrogeomorphic Assessment Report*. At each site, the stream permanent cross-section, longitudinal profile, and substrate (through pebble counts) were surveyed. Each reach location was chosen such that typical conditions of Wolf Run and its tributaries were evaluated, rather than the worst conditions within the stream. As 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.

In general, the streams assessed are over-widened and entrenched such that the channel width and area are larger than expected for streams in the Bluegrass physiographic region (Parola 2007). Entrenchment indicates that flood flows are contained within the stream banks and do not release onto the floodplain where their energy may be dissipated. When streams are entrenched, the velocity of flow is increased during flood events, causing further erosion, and the water table is lowered, resulting in more intermittent stream flows. Over-widened stream channels typically have a lack of pool/riffle habitat and a flat bottom. Together, over-widening and entrenchment impact the macroinvertebrate community negatively because in-stream habitat is reduced, streams go dry more frequently, and macroinvertebrates are swept downstream during flood flows.

Disturbances were observed to some degree at all reaches surveyed. The degree of alteration within the stream 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. There are several exposures of bedrock within the study area. Though the monitored reaches exhibit channel incision and over widening throughout and absence of pools 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.

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 (poor 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
- Channelization

Opportunities for improvement were observed at each reach surveyed and these opportunities are indicated in the reach summaries that follow. Based on the lack of obvious physical constraints in a reach, position in the landscape, etc., reaches W5A, W6, W7, W8, and W9 are considered the highest priority for restoration or enhancement, as shown in Exhibit 27, page IV-6. Locations of manmade dams and severe erosion areas identified by LFUCG during their visual stream assessments are also shown on Exhibit 27 as well as areas of bank armoring or channelization.

a. Wolf Run at Old Frankfort Pike

As the most-downstream reach, this is the largest stream channel surveyed in this assessment. Trash/debris (*i.e.,* shopping carts) were abundant in this reach. Areas of raw, nearly vertical, eroding stream banks were observed in this assessment (Exhibit 27, page IV-6). 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. For this site, the 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. The median particle size in active riffles was coarse to very coarse gravel. This indicates that these substrates provide stable aquatic habitat. However, this reach does have some bedrock-dominated pools and a rather monotonous bed comprised of run/shallow pool 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.

b. McConnell Branch at 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 seems 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. The median particle size in active riffles is medium to coarse gravel. 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

Preston's Cave, a Unique Geological Feature

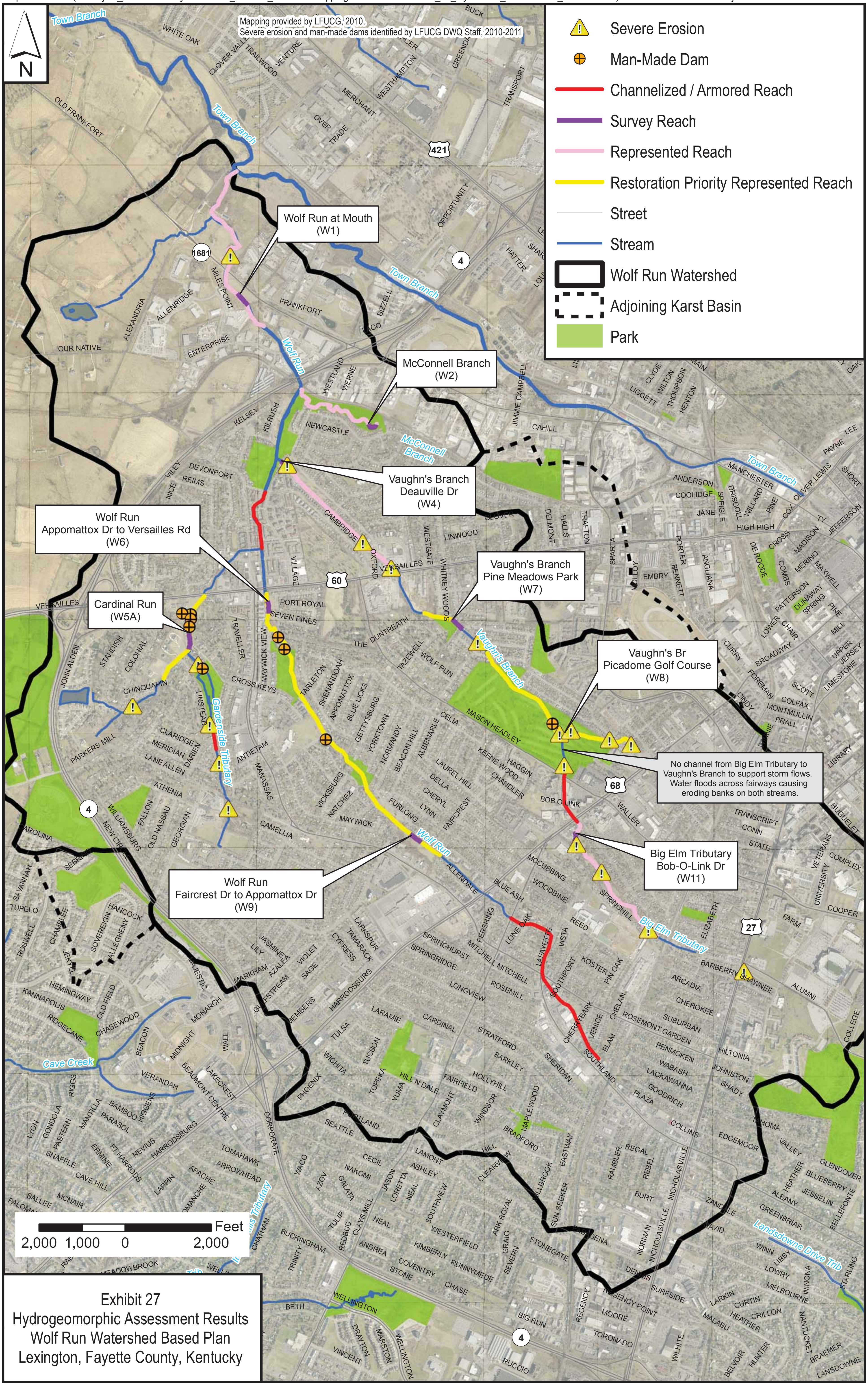


Exhibit 27
Hydrogeomorphic Assessment Results
Wolf Run Watershed Based Plan
Lexington, Fayette County, Kentucky

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 evaluated 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.

c. Vaughn's Branch at Valley Park

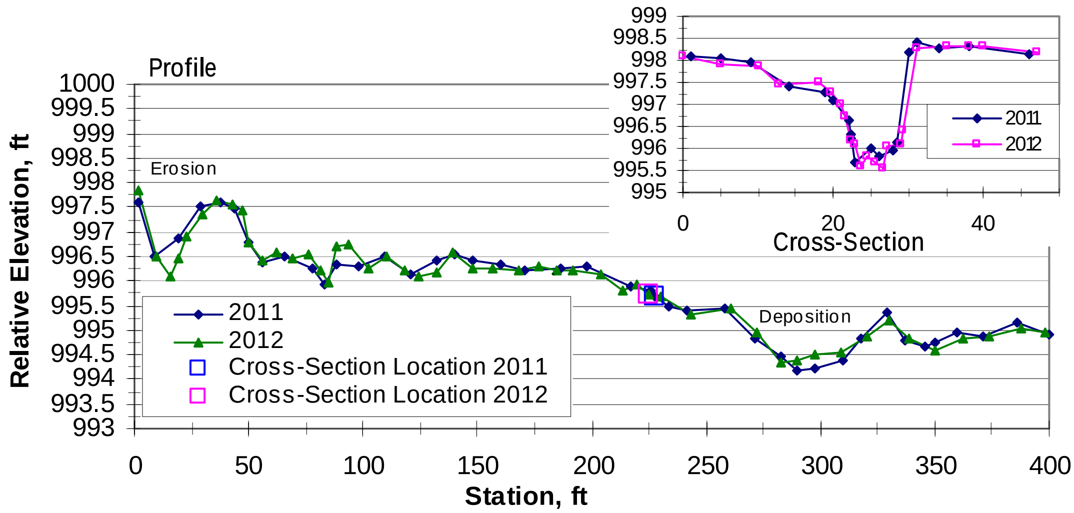
The reach represented by this site is the most downstream portion of Vaughn's Branch, just upstream of its confluence with Wolf Run. As observed during the longitudinal profile survey and as indicated by the habitat assessment data, there is a relatively frequent occurrence of riffles in this section 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. A severe erosion area is located in this reach near the confluence with Wolf Run and has impacted infrastructure (utility pole, stormwater outfall). The longitudinal profile indicated a deep pool on bedrock and the remainder of the reach was predominately riffle and run habitat. The median particle size in active riffles is coarse gravel. The vertical diversity could be enhanced to create more niche habitats for aquatic life. 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.

Erosion and Infrastructure Damage at Vaughn's Branch Mouth

d. Cardinal Run at Parkers Mill Road

This reach, on private property, has tremendous potential for restoration and achieving substantial ecological lift. As such, it is identified as a priority restoration area in the watershed. 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, shown in Figure 5, page IV-8, indicates that the pool is filled in roughly three inches due to deposition, likely from material supplied by the deepening of an upstream pool. 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.

FIGURE 5 – CARDINAL RUN AT PARKERS MILL ROAD, CHANNEL PROFILE AND CROSS-SECTIONAL AREA



e. Wolf Run at 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, stability and riparian vegetation is primarily contributing to this stream's 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. The longitudinal profile surveyed in this assessment indicates long stretches of run/shallow pool habitat, and 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.

f. Vaughn's Branch at 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. As such, this reach has been identified as a priority restoration area.

Erosion on Vaughn's Branch on Picadome Golf Course

g. Vaughn's Branch at 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. This reach shows numerous areas of severe erosion. Due to its location within LFUCG park 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. For this reason, this reach has been identified as a priority restoration area.

Stream Flow and Erosion across Fairways from Big Elm Tributary to Vaughn's Branch

Big Elm tributary contributes flow to Vaughn's Branch within the golf course. However, there is not a stream connecting the two reaches. Under base flow conditions, all of the flow from the Big Elm tributary flows into a large sinkhole. Under flood conditions, the stream flow exceeds the capacity of the sinkhole and 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 as well as deposition of large debris subsequent to storms. This could be remedied by restoration of the channel, though it will impact play at the golf course and require careful planning.

Severe Erosion on Big Elm Tributary near Picadome Sinkhole *h. Wolf Run at Faircrest Drive*

This reach was characterized as having an acceptable frequency of riffles, and three riffles surveyed in this assessment have relatively un-embedded substrate providing some potential habitat. 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. This stream is rather wide and shallow, which diminishes flow depth during dry periods and can stress aquatic species. Substrate data indicates 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. As such this reach has been designated a priority restoration area.

i. Big Elm Tributary at Harrodsburg Road

As observed during the longitudinal profile survey, there is a relatively frequent occurrence of riffles in this section of tributary, which provides aquatic habitat. There are areas where concrete armors the bank and 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. Additionally, finding ways to increase and sustain base flow in this karst subwatershed would improve habitat for aquatic life in this reach.

j. Restoration Measures

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 assessment data in conjunction with the hydrogeomorphic data, the narrow 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 a 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.

B. Volume and Velocity Impacts

In addition to lack of habitat within the watershed, the volume and velocity of stream flows can impact aquatic ecosystems. The high percentage of impervious surface in the watershed causes increased runoff volume and velocities in the watershed. These surfaces, as well as the karst geology of the watershed, also contribute to frequent dry or low flow conditions in the watershed, particularly in the headwaters. The karst hydrograph characterization study was aimed at providing a more comprehensive assessment of these impacts.

Under the study, flow was measured during 11 monitoring events conducted during the period of data logger recording which extended from June 13, 2011 to December 2, 2011. In-stream water levels were recorded every five minutes over that period. Six monitoring events were conducted during base flow while five events measured stream flow during precipitation. Two events were conducted during storms where more than one inch of daily rainfall was recorded at the Bluegrass airport. Precipitation was recorded on 62 of the 185 days in which the data loggers were deployed, or 34 percent of the days in the monitoring period.

In-stream flow measurements and stream geomorphic surveys were utilized to generate stage-discharge curves for each monitoring site. These stream-discharge curves were sufficient to analyze the full range of flows at the mouth of the watershed and the hydrographic rise and fall associated with storm events at other locations.

The study showed that the streams were extremely flashy during storm events, but also sustain frequent and prolonged periods of dry or low flows. The median time to peak of 3.1 hours at the USGS gage at the mouth of the watershed indicates the extent of the flashiness, which is also associated with dramatic flushing events, such as a jump from 1.9 cfs to 1,150 cfs in just 2.6 hours on August 3, during which over 1.8 inches of precipitation were recorded at the Bluegrass airport.

As measured by the USGS gage, stream flows at the mouth of the Wolf Run watershed ranged from 0.46 cfs to 1,150 cfs. The median flow at the site was 7.3 cfs, but only 3.8 percent of the flows exceeded 100 cfs. This indicates an extremely flashy stream system with a quick rise and fall during storm events due to numerous upstream factors including a high percentage of impervious surface and geological factors.

McConnell Branch (W02), which receives most of its flow from Preston's Cave and the upstream McConnell Springs groundwater sources, exhibited the most gradual rise and fall of all the monitoring locations. The low maximum calculated flow of 51 cfs is due to the flow restriction created by the size of the cave opening. Based on field measurements, McConnell Branch comprises an increasingly greater portion of the total flow at the mouth of the watershed as the time since the last precipitation event increases. During field measurements on August 29 when the flow at the mouth of the watershed was measured at 1.1 cfs, which is near the lowest observed over the monitoring period, the flow at McConnell Branch was 0.8 cfs.

At Roanoke Drive (W06), Wolf Run flows exceeding 100 cfs only occurred during 1.1 percent of the monitoring period. The flow is also much lower during median flows, at only 0.58 cfs as compared to 7.3 cfs the mouth of the watershed. Although peak flows at Roanoke Drive were found to approach or exceed the peak flows at the mouth of the watershed during several events, this result is most likely due the margin of error of the calculated flows. This was one of only two locations where the water depth exceeded the top of bank, doing so on three dates, July 7, August 3, and September 4, for a total of 3 hours 25 minutes during the monitoring period. As mentioned previously, flows at water depths that exceeded the top of bank (near 500 cfs) are considered estimates at this site and may be over-predicted. Regardless, the site shows impacts from high velocities and the channel was observed to go dry on occasion.

Further upstream at Faircrest Drive (W09), just upstream of the confluence with Spring Branch, the flows at Wolf Run are much lower, reaching a maximum of 170 cfs, but only 15 percent of flows exceed 1.9 cfs. The site was pooled during field measurements on July 29, indicating that no flow is present during extended dry weather conditions. A known karst window is located upstream at Southbend Drive. On August 29, a measured flow of 0.03 cfs was observed entering this window, with no flow downstream. The measured flow at W09 at this time was 0.01 cfs. Thus, the base flow of Wolf Run at Roanoke Drive is reduced due to the karst re-direction in the upstream area. It is suspected that peak flows are also reduced in this watershed area due to the karst system, but this study was not able to determine the degree of reduction. The wide, bedrock structure of many of the streams upstream of this location may also contribute to increased evaporation during dry weather conditions.

Although Vaughn's Branch (W04) reached a maximum flow of 668 cfs, only 20 percent of the flows were greater than 1.0 cfs. Of the sites assessed in the watershed, Vaughn's Branch had the most measurements below 1.0 cfs. Vaughn's Branch was pooled on July 29, indicating that no flow is present during periods of extended dry weather. The flashiness and frequent dry or low flow conditions are due to numerous factors, including redirection of the flow of the Big Elm tributary into the Picadome sinkhole during base flow conditions, high percentage of impervious surface in the headwaters, and the possibility of other karst features within the subwatershed area.

Big Elm Tributary (W11), in the headwaters of the watershed, was routinely the first site to reach peak flow, as might be expected due to its small watershed area. However, flow levels between one and 10 cfs were sustained longer than other sites with larger watershed areas (Vaughn's Branch, Wolf Run at Faircrest Drive) and the peak flows appear suppressed, most likely due to the restriction of flows at the Picadome sinkhole. This was one of only two sites in which water depth exceeded top of bank, doing so for 10 minutes on August 3. The site does go dry during prolonged dry periods, as shown by the August 29 sampling in which no water was present in the stream.

In addition to quantifying the degree of flashiness in the watershed and the range of flows measured on the tributaries to Wolf Run, the study helped to clarify the relationship between surface and karst groundwater flows, particularly under storm conditions at the confluence of the Big Elm Tributary and Vaughn's Branch. The study found that as the karst conduit's flow capacity is maximized, through upstream inputs such as Wolf Run at Southbend Drive or through the maximized capacity at the spring outlets (McConnel Springs), water begins to back up at the Picadome sinkhole until flood levels are sufficient to allow for the bypass across to Vaughn's Branch. Under these conditions, almost the entire flow from the Big Elm Tributary enters Vaughn's Branch. Once the groundwater system has additional capacity to accept additional flow input, floodwaters begin to decline at the Picadome sinkhole. These multiple inputs into the karst system cause higher flow levels at McConnell Branch to be sustained for longer periods of time while also suppressing the peak flows and lengthening both the rising and falling limbs of the hydrographs in the headwater areas of Wolf Run and the Big Elm Tributary.

Panorama of Flood Waters at Confluence of Big Elm Tributary and Vaughn's Branch

Results also indicate that Best Management Practices to improve the warmwater aquatic habitat in the Wolf Run Watershed should target improving the flow regime. Frequent dry periods impair the ability of a stream to support aquatic life, as do increased occurrence of scouring events in the watershed. Best Management Practices to increase base flow, as well as measures to increase infiltration, storage, or re-direction of stormwater runoff should aid the survival of aquatic life. However, because of the difficulty in restoring base flow in heavily karst areas, efforts to improve the health of the aquatic ecosystem may best be focused in areas with lesser karst influences since these areas have one less potential source of impairment. Areas with reduced karst influence include McConnell's Branch, Cardinal Run, Gardenside Tributary, and the lower portions of Wolf Run and Vaughn's Branch. All areas in the watershed would benefit from efforts to capture or infiltrate stormwater.

C. Water Quality

Monitoring was conducted on 15 days from May 25, 2011 to February 17, 2012 at the locations shown in Exhibit 25, page III-12. "Wet" events, which occurred on 12 percent of the days in the monitoring period, were defined as over 0.1 inch of precipitation occurring after a three-day (72-hour) antecedent dry period. "Dry" events, which occurred on 46 percent of the days in the monitoring period, were defined by no rainfall and at least a three-day (72-hour) antecedent dry period. Events conducted less than 72 hours after precipitation of more than 0.1 inch, which occurred during 42 percent of the period, were categorized as "intermediate" events.

Monthly sampling included four "dry" events, two "wet" events, and four "intermediate" events, one of which was conducted during rainfall. The *E. coli* geomean sampling events are categorized as five intermediate events (one conducted during rainfall) and one dry event. Due to a laboratory error on six of the samples collected on the intermediate July 29 event, re-collection event was performed on August 2 at the six sites to allow for the geomean calculations.

Appendix F contains the full *Watershed Monitoring Report*.

1. Benchmarks

In order to evaluate the nature and extent of impairments in the Wolf Run Watershed, results were compared to applicable water quality benchmarks. Both regulatory and non-regulatory benchmarks are applicable for this analysis. Regulatory criteria are specified for parameters in which a given concentration of the pollutant is directly linked with impairment in the designated use. For other parameters, such as nutrients, specific conductance, suspended solids, or dissolved solids, no regulatory numeric standard has been established due to the variable relationship between biological integrity and concentration levels in different streams. Only narrative criteria have been established due to the difficulty in determining impairment thresholds for these parameters as well as the natural geographic variation of these parameters. The benchmarks used for this analysis are summarized in Table 23.

TABLE 23 – WARMWATER AQUATIC HABITAT STANDARDS

Parameter	Warmwater Aquatic Habitat Standard	Type
pH	6.0 and 9.0 SU, and not to fluctuate more than 1.0 SU over 24 hours	Regulatory WAH
Temperature	< 31.7°C (89°F)	Regulatory WAH
Dissolved oxygen	> 5.0 mg/L as a 24-hour average; or > 4.0 mg/L for instantaneous	Regulatory WAH
Un-ionized Ammonia*	< 0.05 mg/L*	Regulatory WAH
Fecal Coliform**	200 CFU/100mLs as 30-day geometric mean, or 400 CFU/100mLs as an instantaneous measurement	Regulatory PCR
Fecal Coliform**	1000 CFU/100mLs as 30-day geometric mean, or 2000 CFU/100mLs as an instantaneous measurement	Regulatory SCR
*E. coli***	130 CFU/100mLs as 30-day geometric mean, or 240 CFU/100mLs as an instantaneous measurement	Regulatory PCR
Total Phosphorus as P	0.35 mg/L	Non-regulatory WAH
Total Nitrogen as N	3.0 mg/L	Non-regulatory WAH
Ammonia (as N)	0.1 mg/L	Non-regulatory WAH
Specific Conductance	650 µS/cm	Non-regulatory WAH
Total Dissolved Solids	373 mg/L	Non-regulatory WAH
Total Suspended Solids	80 mg/L	Non-regulatory WAH

NOTE: The following abbreviations are utilized for the designated uses: warmwater aquatic habitat (WAH), primary contact recreation (PCR), secondary contact recreation (SCR).
**Un-ionized ammonia shall be determined from values for total ammonia as N, in mg/l, pH and temperature, by means of the equation: un-ionized ammonia (mg/L) = 1.2[Total ammonia as N / (1 + 10^{pKa-pH})], where pKa = 0.0902 +[2730/(273.2 +T_c)] and T_c = temperature, °C.*
***Geometric mean based on not less than five samples taken during a 30-day period. Instantaneous standard is not to be exceeded in 20% or more of all samples taken during a 30-day period. If less than five samples are taken in a month, this standard applies.*

The regulatory statute for surface waters in Kentucky is found in 401 KAR 10:031. The statute provides minimum water quality standards for all surface waters as well as specific standards that apply to particular designated uses. All streams monitored have designated uses of warmwater aquatic habitat (WAH), primary contact recreation (PCR), secondary contact recreation (SCR), and fish consumption (FC). Warmwater aquatic habitat standards apply for the protection of productive warm water aquatic communities, fowl, animal wildlife, arboreous growth, agricultural, and industrial uses. Standards for primary contact recreation (PCR) are applicable to full body contact during the recreation season of May 1 through October 31. Secondary contact recreation (SCR) standards are applicable to partial body contact, with minimal threat to public health due to water quality, and these standards apply for the entire year.

For other parameters, no regulatory numeric standard has been established due to the variable relationship between biological integrity and concentration levels in different streams. Multiple factors are impacting warmwater aquatic habitat use of the Wolf Run Watershed, including poor riparian and in-stream habitat and poor hydrology/flow regime as well as elevated water quality parameters. Because of the uncertainty in assigning definitive thresholds for these parameters as well as the feasibility and cost-effectiveness of reducing concentrations, a phased approach was utilized in the development of benchmarks for non-regulatory water quality parameters.

Under this phased approach, non-regulatory reference points are initially established higher than reference conditions since the reference levels may be well below the level necessary to restore support of the use. These target levels are established based the extent and magnitude of the problem as well as technological feasibility, cost, and achievability. These goals would be re-assessed through the watershed planning process on regular time intervals and lowered if the designated use does not become fully supported through the implementation plan efforts when target levels are achieved. Table 23, page IV-14, lists the non-regulatory reference points for the Wolf Run Watershed. These levels were developed in consideration of the recommendations made by KDOW, are applicable only for the Wolf Run Watershed, and are not intended to have any regulatory use.

The rationale behind the selection of these non-regulatory reference points is as follows. The nutrient levels (total phosphorus at 0.35 mg/L and total nitrogen at 3.0 mg/L) were each established between the 75th and 90th percentile concentrations for reference reaches in the Inner Bluegrass. The ammonia benchmark of 0.1 mg/L was near the 75th percentile for the Wolf Run data collected. These higher concentrations were utilized based on published literature (Pond *et al.* 2003), which indicates that nutrient concentrations are not well correlated with macroinvertebrate metrics in the Bluegrass Bioregion. The main stem of the Ohio River has a specific conductance limit of 800 µS/cm, which was considered too high for this region. The benchmark of 650 µS/cm was established near the average of the Wolf Run sampling site medians. The total dissolved solids benchmark was derived based on the ratio to conductivity as measured in the study. The total suspended solids benchmark was established at 80 mg/L based on a number of studies that indicate that concentrations above this level impact fisheries (as listed in Rowe *et al.* 2003).

2. Watershed Concentrations

Based on the analysis of all monitoring results, multiple factors are impacting the water quality in the Wolf Run watershed. Concentrations of nitrogen, phosphorus, dissolved oxygen, ammonia, specific conductance, suspended solids, and *E. coli* each exceeded benchmarks for one or more events. Exhibit 28, page IV-16, and Table 24, page IV-17, identify the relative priority of remediation of each site by parameter. Locations of abundant algal growth and low dissolved oxygen levels are also indicated on Exhibit 28. All sites with high priority require reductions in order to achieve regulatory or target loading levels. Low and medium priority levels were determined by the relative frequency by which reference points were exceeded. Overall, Spring Branch (W10) and the Big Elm Tributary (W11) are the worst areas in the watershed for water quality. The average results for the monthly sampling events that included four “dry” events, two “wet” events, and four “intermediate” events are shown in Tables 25 through 27, pages IV-17 through IV-19.

Map Document: (P:\Project_Files\Kentucky\KY10-030_LFUCG_WolfRun\Mapping\GIS\Exhibits\Exhibit_28_Water_Quality_Results.mxd) 7/24/2012 -- 11:27:46 AM sje

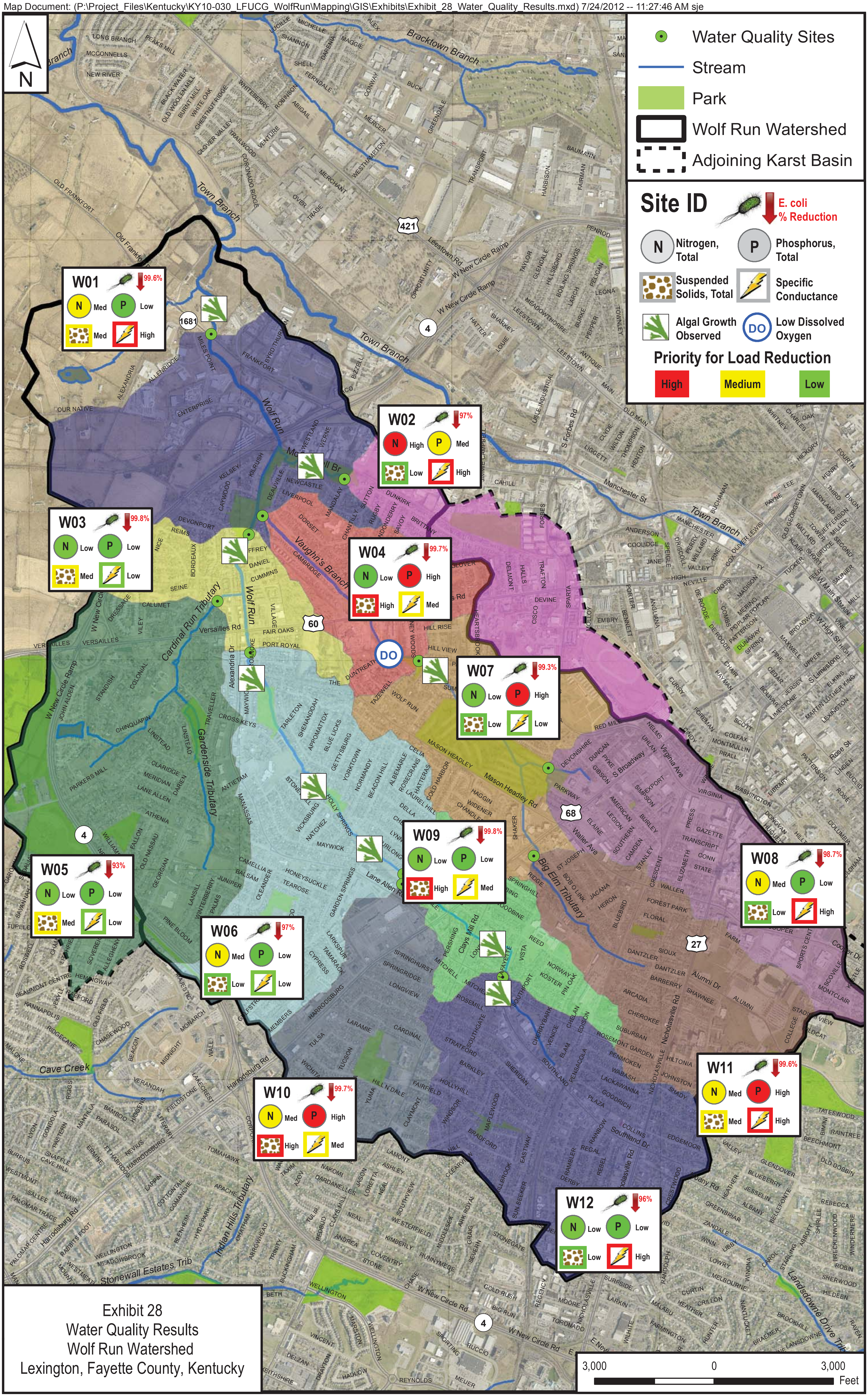


Exhibit 28
Water Quality Results
Wolf Run Watershed
Lexington, Fayette County, Kentucky

TABLE 24 – PRIORITY OF SITES FOR POLLUTANT REDUCTION BY PARAMETER

Parameter	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12
E. coli	High	High	High	High	High	High	High	High	High	High	High	High
Total Nitrogen	Medium	High	Low	Low	Low	Medium	Low	Medium	Low	Medium	Medium	Low
Total Phosphorus	Low	Medium	Low	High	Low	Low	High	Low	Low	High	High	Low
Total Suspended Solids	Medium	Low	Medium	High	Medium	Low	Low	Low	High	High	Medium	Low
Specific Conductance	High	High	Low	Medium	Low	Low	Low	High	Medium	Medium	High	High

NOTE: High priority sites require a loading reduction or the concentration exceeded the benchmark in more than 50% of the measurements. Low priority sites had concentrations that exceeded the non-regulatory indicator level for less than 40% of samples for nitrogen, less than 30% for phosphorus, 0% for suspended solids, and less than 20% for specific conductance.

TABLE 25 – DRY WEATHER EVENT AVERAGES FOR WOLF RUN WATERSHED

Parameter	Unit	Benchmark	W01, WR at Old Frankfort	W02, Preston's Cave	W03, WR at Valley Park	W04, Vaughn's at Valley Park	W05, Cardinal at Devonport	W06, WR at Wolf Run Park	W07, Vaughn's at Pine Meadow	W08, Vaughn's at Picadome	W09, WR at Faircrest Dr	W10, Springs Branch	W11, Big Elm at Harrodsburg	W12, WR at Lafayette Pkwy
Dissolved Oxygen	mg/L	> 4.0	8.6	7.7	14.1	8.9	8.1	11.1	6.9	12.8	12.1	10.2	9.1	10.0
pH	SU	6.0 to 9.0	7.9	7.1	8.1	8.1	7.7	8.1	6.8	8.2	7.9	7.7	7.7	7.8
Specific Conductivity	µS/cm	650	708	779	627	629	616	588	545	1174	856	630	956	672
E. coli	CFU/100mLs	130 / 240	617	1691	537	3087	511	1404	2147	1220	2069	590	1095	801
Fecal coliform	CFU/100mLs	200 / 400	972	2202	767	1796	529	1679	1650	1191	2418	794	1702	728
Suspended Solids, Total	mg/L as P	80	4.7	5.3	5.0	1.7	5.3	7.3	3.0	5.0	26.7	8.7	11.0	10.0
Dissolved Solids, Total*	mg/L as P	373	372	429	345	349	343	327	310	624	486	363	554	419
Alkalinity, Total	mg/L as CaCO3	-	214	200	197	222	214	189	223	191	224	196	199	170
Hardness, Total	mg/L as CaCO3	-	268	282	259	270	267	258	259	348	296	260	324	266
Ammonia	mg/L as N	0.1	0.022	0.011	0.015	0.015	0.016	0.013	0.019	0.018	0.012	0.010	0.019	0.011
Nitrite	mg/L as N	-	0.019	0.008	0.018	0.008	0.015	0.021	0.023	0.019	0.021	0.017	0.013	0.011
Total Kjeldahl Nitrogen	mg/L as N	-	0.08	0.43	0.04	0.04	0.07	0.07	0.04	0.34	0.28	0.70	0.55	0.04
Nitrate	mg/L as N	-	2.60	3.35	2.30	1.77	2.48	2.98	2.65	3.50	2.78	3.58	3.80	1.85
Total Nitrogen	mg/L as N	3.0	2.70	3.79	2.36	1.82	2.55	3.07	2.71	3.86	3.08	4.29	4.36	1.90
Ortho-phosphorus	mg/L as P	-	0.283	0.297	0.290	0.323	0.307	0.315	0.418	0.192	0.261	0.270	0.277	0.123
Phosphorus, Total	mg/L as P	0.35	0.30	0.30	0.29	0.33	0.31	0.33	0.41	0.26	0.30	0.35	0.33	0.14

**Dissolved solid results should be utilized for screening purposes only due to the data quality.*

TABLE 26 – INTERMEDIATE EVENT AVERAGES FOR WOLF RUN WATERSHED

Parameter	Unit	Benchmark	W01, WR at Old Frankfort	W02, Preston's Cave	W03, WR at Valley Park	W04, Vaughn's at Valley Park	W05, Cardinal at Devonport	W06, WR at Wolf Run Park	W07, Vaughn's at Pine Meadow	W08, Vaughn's at Picadome	W09, WR at Faircrest Dr	W10, Springs Branch	W11, Big Elm at Harrodsburg	W12, WR at Lafayette Pkwy
Dissolved Oxygen	mg/L	> 4.0	8.9	7.3	10.6	10.0	7.9	9.3	9.0	10.2	10.0	9.1	8.5	9.9
pH	SU	6.0 to 9.0	7.4	7.0	7.6	7.5	7.5	7.7	7.3	7.9	7.8	7.7	7.8	7.8
Specific Conductivity	µS/cm	650	587	739	525	577	586	504	524	763	589	544	703	667
E. coli	CFU/100mLs	130 / 240	7063	5534	6730	3332	3278	2665	4896	4278	4958	1716	4744	2017
Fecal coliform	CFU/100mLs	200 / 400	5118	4405	6286	7803	3759	8437	6947	3524	5281	3428	5732	3329
Suspended Solids, Total	mg/L as P	80	11.8	14.0	7.3	6.5	8.5	6.0	27.0	7.5	5.0	4.8	11.0	8.2
Dissolved Solids, Total*	mg/L as P	373	429	405	280	300	310	259	298	633	276	303	457	387
Alkalinity, Total	mg/L as CaCO3	-	160	152	148	170	161	150	151	144	149	162	161	153
Hardness, Total	mg/L as CaCO3	-	207	236	208	216	230	210	207	255	228	222	261	221
Ammonia	mg/L as N	0.1	0.027	0.020	0.019	0.019	0.049	0.021	0.038	0.033	0.013	0.016	0.022	0.017
Nitrite	mg/L as N	-	0.019	0.012	0.022	0.021	0.032	0.010	0.034	0.041	0.008	0.017	0.014	0.021
Total Kjeldahl Nitrogen	mg/L as N	-	0.40	0.30	0.27	0.40	0.36	0.29	0.37	0.37	0.39	0.28	0.55	0.37
Nitrate	mg/L as N	-	2.19	2.60	2.35	2.09	2.18	2.55	2.03	2.57	2.33	3.03	2.80	2.10
Total Nitrogen	mg/L as N	3.0	2.61	2.91	2.64	2.50	2.56	2.85	2.44	2.98	2.72	3.32	3.36	2.49
Ortho-phosphorus	mg/L as P	-	0.185	0.273	0.268	0.278	0.287	0.271	0.323	0.152	0.227	0.248	0.324	0.132
Phosphorus, Total	mg/L as P	0.35	0.29	0.33	0.29	0.28	0.31	0.26	0.40	0.16	0.24	0.26	0.37	0.15

**Dissolved solid results should be utilized for screening purposes only due to the data quality.*

TABLE 27 – WET WEATHER EVENT AVERAGES FOR WOLF RUN WATERSHED

Parameter	Unit	Benchmark	W01, WR at Old Frankfort	W02, Preston's Cave	W03, WR at Valley Park	W04, Vaughn's at Valley Park	W05, Cardinal at Devonport	W06, WR at Wolf Run Park	W07, Vaughn's at Pine Meadow	W08, Vaughn's at Picadome	W09, WR at Faircrest Dr	W10, Springs Branch	W11, Big Elm at Harrodsburg	W12, WR at Lafayette Pkwy
Dissolved Oxygen	mg/L	> 4.0	22.0	17.4	19.4	16.5	20.2	19.5	19.3	20.2	20.3	20.8	18.3	19.2
pH	SU	6.0 to 9.0	7.6	7.2	7.6	7.7	7.5	7.7	8.0	7.9	7.9	7.9	7.9	7.8
Specific Conductivity	µS/cm	650	228	725	184	239	200	427	96	98	117	74	622	376
E. coli	CFU/100mLs	130 / 240	58244	232	105493	48788	1600	5024	21464	12535	88667	66248	57048	4012
Fecal coliform	CFU/100mLs	200 / 400	22704	467	34347	29759	1620	4514	9929	5946	39620	33532	31811	3253
Suspended Solids, Total	mg/L as P	80	108.0	33.5	117.0	141.5	66.5	30.5	44.5	41.5	131.5	180.0	65.5	19.0
Dissolved Solids, Total*	mg/L as P	373	174	398	84	138	118	110	73	86	52	209	385	177
Alkalinity, Total	mg/L as CaCO3	-	115	221	86	82	72	151	50	55	44	44	131	118
Hardness, Total	mg/L as CaCO3	-	118	225	123	126	100	202	98	94	99	90	240	188
Ammonia	mg/L as N	0.1	0.127	0.023	0.141	0.118	0.195	0.085	0.184	0.144	0.228	0.111	0.079	0.086
Nitrite	mg/L as N	-	0.019	0.009	0.024	0.020	0.010	0.022	0.015	0.021	0.025	0.017	0.018	0.011
Total Kjeldahl Nitrogen	mg/L as N	-	0.04	0.04	0.04	0.04	0.04	0.04	0.26	0.23	0.33	0.04	0.04	0.04
Nitrate	mg/L as N	-	0.61	3.15	0.66	0.27	1.17	1.03	0.28	0.27	0.35	0.29	1.01	1.04
Total Nitrogen	mg/L as N	3.0	0.67	3.20	0.72	0.33	1.22	1.09	0.56	0.52	0.70	0.34	1.06	1.09
Ortho-phosphorus	mg/L as P	-	0.251	0.274	0.206	0.240	0.166	0.310	0.214	0.174	0.295	0.222	0.351	0.120
Phosphorus, Total	mg/L as P	0.35	0.35	0.47	0.34	0.79	0.27	0.37	0.44	0.30	0.35	0.82	0.47	0.20

**Dissolved solid results should be utilized for screening purposes only due to the data quality.*

In-stream flow was measured concurrent with grab sample collections for each event. The results of these measurements are shown in Table 28, page IV-20. Wet weather conditions are typically one to two orders of magnitude higher than dry weather conditions. Also, during dry weather conditions, the groundwater flow from Preston's Cave (W02) represents a much greater percentage of the flow contribution at the mouth of the watershed due to the karst re-direction of surface flow from the headwaters of Vaughn's Branch and Wolf Run into the groundwater system. Because flow at W02 is primarily due to groundwater sources, the difference between wet and dry weather flows is much less than at other locations in the watershed.

TABLE 28 – FLOW MEASUREMENTS FOR ALL EVENTS

Date	Event	Flow (cfs)											
		W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12
5/25/11	Intermediate	30.6	10.3	11.5	1.6	5.0	7.0	0.5	0.7	1.0	1.5	2.3	1.4
6/13/11	Dry	2.7	1.3	0.5	0.02	0.4	0.4	Pooled	Pooled	0.3	0.01	Dry	Pooled
7/8/11	Intermediate while Raining – *E. coli*	36.2	15.6	Too Fast	Too Fast	Too Fast	Too Fast	9.7	173.0	Too Fast	20.6	Too Fast	21.5
7/11/11	Intermediate	7.8	4.2	3.0	0.4	1.4	1.6	0.2	0.3	0.4	0.6	0.6	0.02
7/15/11	Dry – *E. coli*	6.3	3.9	0.2	1.7	0.5	1.1	Pooled	0.04	0.1	0.4	0.2	0.05
7/25/11	Intermediate – *E. coli*	6.3	4.0	8.7	2.8	0.1	3.1	3.9	3.0	2.0	0.9	1.6	1.5
7/29/11	Intermediate – *E. coli*	1.9	1.4	0.3	<0.01	0.2	0.3	0.02	0.2	<0.01	0.5	0.05	0.04
8/2/11	Intermediate – *E. coli* Recollection	---	---	---	---	---	0.3	<0.01	0.5	0.01	0.4	<0.01	---
8/29/11	Dry	1.1	0.8	0.04	0.03	0.10	0.15	<0.01	0.01	0.01	0.11	Dry	0.03
9/30/11	Dry	10.9	2.4	2.6	0.4	1.6	1.1	0.04	0.14	0.12	0.5	0.14	0.04
10/13/11	Wet	69.9	8.6	20.7	13.3	1.0	0.04	9.1	5.8	39.6	20.1	1.9	0.2
11/16/11	Intermediate while Raining	47.9	16.8	16.0	5.0	6.7	12.1	3.9	3.8	6.2	1.7	4.8	11.8
12/12/11	Dry	12.8	3.9	4.2	0.7	2.4	1.8	0.14	0.08	0.6	0.8	0.3	0.4
1/11/12	Wet	148.9	14.4	96.7	55.9	11.7	47.8	28.8	20.0	55.1	18.8	19.0	23.8
2/17/12	Intermediate	11.7	5.1	3.1	0.52	1.8	2.4	0.02	0.16	0.26	0.84	0.6	0.41
Wet Average		109.4	11.5	58.7	34.6	6.4	23.9	19.0	12.9	47.4	19.5	10.5	12.0
Intermediate Average		17.7	7.0	7.1	1.7	2.5	4.4	1.4	1.4	1.6	1.0	1.7	2.5
Dry Average		6.8	2.5	1.5	0.6	1.0	0.9	0.1	0.1	0.2	0.4	0.2	0.1

NOTE: Intermediate average excludes the event on 7/8/2011 in which most sites could not be measured due to high velocities. Pooled and dry sites were excluded from calculations. For streams with flow levels less than 0.01 cfs, 0.005 cfs was utilized for calculation purposes.

Overall, the most severe problem throughout the watershed is the pathogen indicator parameters, *E. coli* and fecal coliform, for which averages were above the instantaneous benchmark levels at all sites for all event types. Only 17 percent of the fecal coliform results were below the instantaneous PCR limit of 400 MPN/100mLs while 38 percent were below the SCR limit of 1,000 MPN/100mLs. *E. coli* concentrations only met the instantaneous PCR limit of 240 MPN/100mLs in 14 percent of the results. Even lower percentages met the criteria for the geometric mean over a 30-day period for fecal coliform (10 percent below 200 CFU/100mLs) or *E. coli* (seven percent below 130 CFU/100mLs). The geometric mean concentrations are shown in Table 29.

TABLE 29 – GEOMETRIC MEAN CONCENTRATIONS OF FECAL INDICATORS COMPARED TO WATER QUALITY CRITERIA

Site	W01	W02	W03	W04	W05	W06	W07*	W08	W09	W10	W11	W12	WQS
Geomean *E. coli* (MPN/100mLs)	3009	1366	3031	2237	1482	2267	9071	2946	6395	1353	4795	770	130
Geomean Fecal Coliform (MPN / 100mLs)	3074	1188	4354	5528	1559	5294	8477	1974	5861	3274	6221	2266	200

**Geometric mean of only four samples due to pooled water during 7/15/11 event.*

With a human source likely for much of this load (Brion 2011), these levels pose a risk for recreational users of waters within the Wolf Run Watershed and reductions will be necessary throughout the watershed. Average concentrations varied considerably by event type, but generally wet weather events had much higher concentrations than dry weather events. W08 and W02 were each exceptions with W08 being high during dry weather and W02 being low during wet weather. Despite the high concentrations of fecal coliform and *E. coli*, no sanitary sewer overflows were documented by LFUCG for the dates in which the wet weather sampling was conducted. This may indicate sanitary sewer exfiltration from sources other than known overflowing manhole locations or additional sources of input including urban wildlife, pet waste, or other sources.

Abundant algal growth was observed at multiple areas across the Wolf Run Watershed as identified in Exhibit 28, page IV-16. This algal growth is cause by excessive nutrient loading and lack of stream shading and causes low dissolved oxygen levels and high pH. Aquatic plants and algae, which produce oxygen during the day through photosynthesis, consume dissolved oxygen after sunset, when no photosynthesis occurs. If a large volume of aquatic plant material is present in the stream, the plants may use so much dissolved oxygen that conditions toxic to aquatic life are produced at night. Additionally, abundant decaying plant matter leads to excessive oxygen use during bacterial decomposition. Fish require at least 5 to 6 mg/L of dissolved oxygen for normal activity. Levels below 4 mg/L are stressful, and levels below 2 mg/L are lethal. No fish kills were known to occur during the monitoring period.

Significant Algal Growth on McConnell Branch

Dissolved oxygen levels were detected below the instantaneous water quality limit (4.0 mg/L) once on August 29, 2011 at W07 and were once found below the chronic water quality limit (5.0 mg/L) at W04. All other measurements meet the minimum water quality standard. The highest dissolved oxygen levels recorded, 22.0 mg/L at W12, occurred along with the highest pH levels measured. Algal growth was extremely abundant at the site during the measurements and bubbles from the algae could be observed in the near-stagnant water.

The pH values ranged from a maximum of 8.6 SU to a low of 6.5 SU, each measured under dry conditions. All values were within the warmwater aquatic habitat standards of 6.0 to 9.0 SU. The limestone bedrock geology and heavy algal growth in some areas are suspected as contributing to the higher pH levels observed in the watershed.

The nutrient levels in the watershed were found to be high, contributing to abundant algal growth, but also contributing to other short and long term effects on stream ecosystems, including hypoxia in the Gulf of Mexico.

The total nitrogen concentrations were lowest during wet weather and highest during dry weather. Total nitrogen results ranged from below the reporting limit to 5.6 mg/L (at W11). W02 had concentrations above the non-regulatory reference point of 3.0 mg/L the most frequently, in seven of 10 events. W10, W08, and

W11 also exceeded the non-regulatory reference point during at least half of the measurements. The total nitrogen was comprised primarily of nitrate in all events, with total kjeldahl nitrogen and nitrite commonly below detection limits. At most, nitrite was only five percent of the total nitrogen. Total kjeldahl nitrogen was typically less than 20 percent of the total nitrogen, but comprised 44 to 47 percent during wet events at sites W07, W08, and W09. Thus, nitrate is the most common form of nitrogen in the watershed.

Ammonia, a type of nitrogen, results ranged from less than 0.015 mg/L to 0.306 mg/L. Unlike the total nitrogen, wet weather averages for ammonia were much higher at all sites (except W2) than dry or intermediate averages. All sites except W02 had one measurement above the non-regulatory reference point of 0.1 mg/L; five sites had two measurements above that concentration. All unionized ammonia concentrations were well below the warmwater aquatic habitat regulatory limit of 0.05 mg/L.

Phosphorus was measured in two forms: orthophosphorus and total phosphorus. Orthophosphorus is the available form of phosphorus that can be utilized by plants and algae while total phosphorus includes orthophosphorus and other forms. Orthophosphorus is a dissolved form of phosphorus while total phosphorus includes both dissolved and particle-bound phosphorus. Background concentrations of phosphorus approached the non-regulatory reference point of 0.35 mg/L throughout the watershed, with orthophosphorus averaging approximately 0.25 mg/L for all conditions and total phosphorus averaging approximately 0.29 mg/L for dry and intermediate events. Orthophosphorus ranged from below the reporting limit to a maximum of 0.604 mg/L, but was fairly consistent across event types. Sites W12 and W08 were consistently lower than other sites while sites W11 and W07 were consistently higher. Total phosphorus concentrations were much higher for wet weather than dry or intermediate averages. Wet weather events averaged 0.428 mg/L., due in part to increased suspended sediment levels measured during these events. The highest measured total phosphorus was 1.12 mg/L. All sites except W12 had at least one measurement above the non-regulatory reference point of 0.35 mg/L. Site W07 had concentrations above that level most frequently, exceeding it during six of the 10 measurements.

Total suspended solids were, as expected, higher in wet weather events than during dry and intermediate events. Sites W01, W03, W04, W09, and W10 each had suspended solid levels exceeding 80 mg/L with a high of 200 mg/L measured at W10 on October 13. All of these elevated events occurred during wet events. During wet weather events with high concentrations of suspended sediment, the color of the water is typically black or gray rather than brown like the soil color. Although erosion is a contributor to the suspended sediment load, the color of the turbidity indicates that stormwater runoff is a greater contributor to suspended sediments in Wolf Run.

Grey Colored Stormwater on Vaughn's Branch Upstream of Picadome Golf Course

Water temperature ranged from 5.3˚C (41.5˚F) to 26.0˚C (78.8˚F). All values are below the warmwater aquatic habitat maximum of 31.7°C (89°F). For the period sampled, the greatest variability in temperature was shown at W08 and W12 due to the shallow bedrock nature of these streams. These sites, as well as W03 and W06, were also slightly warmer than other sites on average. Sparse canopy coverage of the wide, shallow streams contribute to these higher averages. W02, located at Preston's Cave, had the least variability in temperature measurements due to the groundwater flow source regulating temperature fluctuations.

Specific conductance levels are frequently elevated at several locations in the watershed. Sites W02, W11, W08, W12, and W01 all exceeded 650 µS/cm in more than half of the measurements at those sites, particularly under dry and intermediate conditions. Sites W03, W05, W06, and W07 had the lowest conductivity levels with only one measurement exceeding 650 µS/cm during the monthly monitoring. For the Wolf Run Watershed, total dissolved solids and specific conductance were related such that the dissolved solids concentration is typically approximately 57 percent of the specific conductance value. High conductivity or total dissolved solids may be due to nutrients, metals, or other compounds from sources such as natural geology or pollutants. While background levels due to geology are approximately 375 µS/cm (based on calculations using the total alkalinity and hardness concentrations), additional dissolved ion contributions can elevate these levels to above 650 µS/cm. Additional studies should examine the prevalence of chloride as volunteer data indicates it may be a large contributor to the conductivity in Wolf Run.

In addition to the monthly conductivity measurements, a conductivity survey was conducted throughout the Wolf Run watershed, the results of which are presented in a *Conductivity Survey Report* (Appendix C). The study provided a "snapshot" of low flow, dry weather conductivity in the Wolf Run Watershed, shown in Exhibit 29, page IV-24. In agreement with the monthly sampling results, high conductivity levels were measured on the Big Elm Tributary upstream of Nicholasville Road, Vaughn's Branch headwaters, and Wolf Run headwaters along Southland Drive. Additionally, an oily sheen and increase in conductivity in Wolf Run downstream of Harrodsburg Road, an increase from McConnell Springs to Preston's Cave, and a drop in conductivity on Picadome Golf Course were findings that should be investigated further. Additional monitoring should be conducted at these locations to indicate whether these problems are temporal or long-term in nature. Investigations into the root causes should be initiated in order to provide the most effective remediation.

In an effort independent of this study, the University of Kentucky has conducted extensive investigations to determine the source of the high conductivity levels from sources within their MS4 area. In a *Water Quality Investigation Report* dated November 3, 2011, the University explains their findings to date related to high conductivity levels noted in Vaughn's Branch and Big Elm Tributary.

For the headwaters of Vaughn's Branch, investigations indicated that a potential source for the high conductivity levels include runoff from South Limestone and commercial gas stations, natural sources including a suspected historic stream flowing under Seaton Center, groundwater infiltration into the stormsewer system, and several springs with high conductivity levels. The investigations identified a leaking cooling tower and greenhouse cooling equipment as contributing sources as well. The leaking cooling tower water was redirected into the sanitary sewer system in mid-October 2011 and the University is preparing short and long-term retrofitting plans to prohibit the discharge of non-contact cooling water originating from the greenhouses. Thus, one source of conductivity has been removed from the watershed and further work is ongoing by the University to determine other sources.

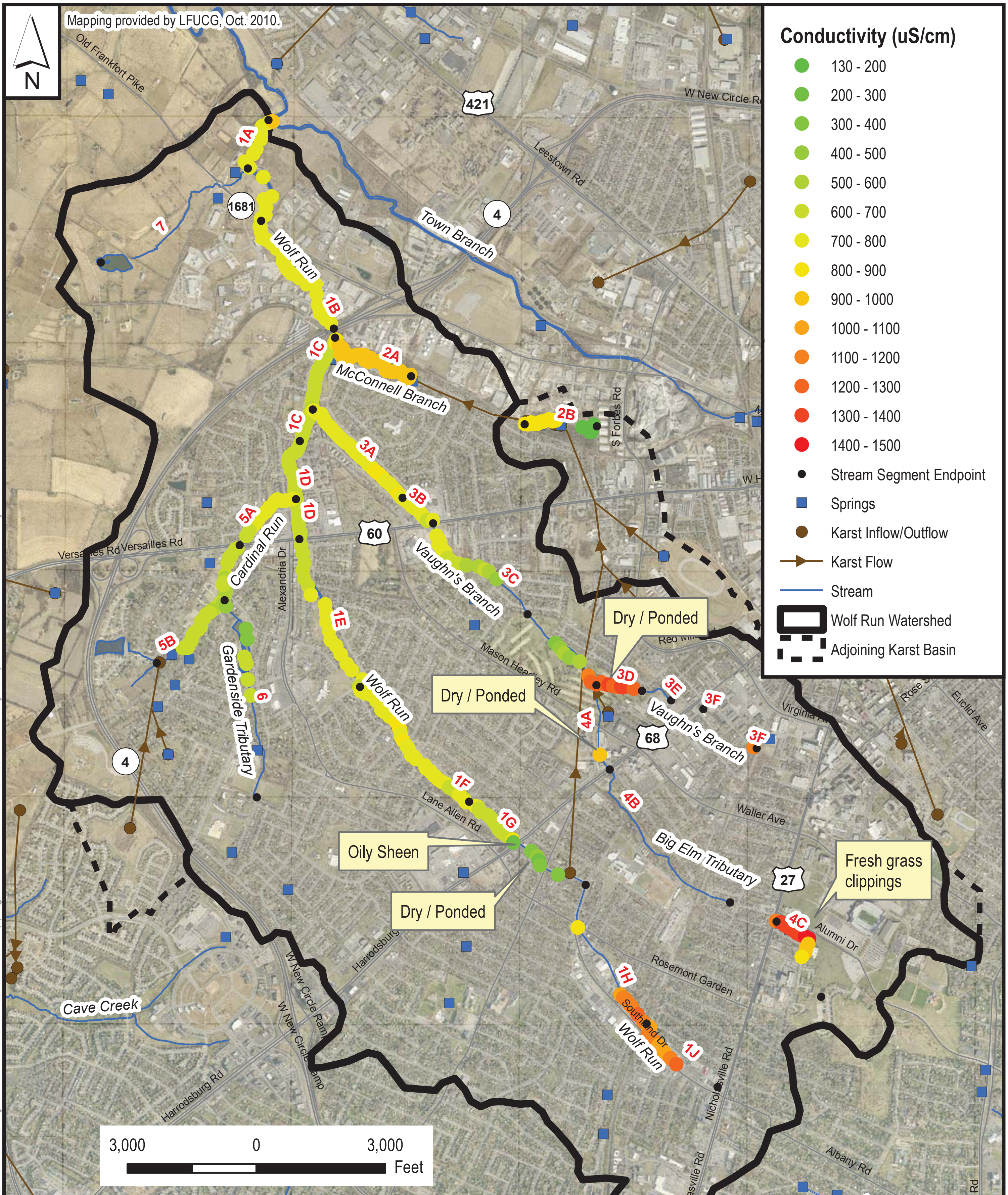


Exhibit 29
Conductivity Survey Results
Wolf Run Watershed Based Plan
Lexington, Fayette County, Kentucky

Conductivity readings were measured by the Friends of Wolf Run using calibrated meters during low flow conditions between September 17 and October 11, 2011.

Map Document: (P:\Project_Files\Kentucky\KY10-030_LFUCG_WolfRun\Mapping\GIS\Exhibits\Exhibit_29_Conductivity.mxd) 9/14/2012 -- 11:21:49 AM sje

For the Big Elm Tributary headwaters, the dominant source of the high conductivity levels was traced to two natural springs (called "Parking Lot Spring" and "Detention Basin Spring") that are located in the detention basin upstream of the pipe outfall near Alumni Drive. The University also noted a pipe near Nicholasville Road that was discharging high levels of conductivity and a small dry-weather discharge from Shawneetown Apartments with high *E. coli* levels (potentially indicating a sanitary waste source). The University plans to continue investigations of these sources.

3. Pollutant Loads and Reduction Targets

In order to calculate the annual loads at each site, concentrations for each parameter were first averaged for each event type (dry, wet, intermediate). Second, a flow was determined for each event type. For intermediate and dry events, the average of the measured flow was utilized. For wet weather, average measured flow at the mouth of the watershed (W01) was multiplied by the percentage of the total watershed area located upstream of each site to produce an "engineered" wet weather flow for each site (flow at mouth scaled for each site based on subwatershed drainage area). Third, for each event type the average concentration and engineered flow were multiplied by the concentration and a conversion factor to develop a daily load value for each site. Lastly, an annual load was calculated by weighting the daily load for each event type by the percentage of days in the period in which that type of condition was present (0.46 for dry, 0.42 for intermediate, and 0.12 for wet) and multiplying by 365.

To calculate the target load for each site, this same process was utilized, substituting the benchmark concentrations for the measured concentrations. Although the wet weather events occurred at a lower frequency than intermediate or dry events, the target load contribution during these events composed over 50 percent of the total load for all sites, except W02, due to the higher flows associated with these events. This target load was then subtracted from the actual annual load to determine the load reduction needed to reach the target load.

The load reductions required for the Wolf Run Watershed are summarized in Table 30, page IV-26, by subwatershed area. Over 90 percent load reductions are required for *E. coli* at all sites, with the most significant loading coming during wet weather. Remediation of the sanitary sewer system, including private laterals as well as public lines, will be critical to reducing the load in the watershed. For nitrogen, load reductions are necessary at Preston's Cave Spring (W02) but due to the karst influence, remediation for these levels should be targeted to the area of the Town Branch Watershed captured by the McConnell Springs drainage as well as in the Big Elm Tributary subwatershed area (W11). Ammonia levels were high at many locations in the watershed during wet weather events, but should be addressed through efforts to reduce the fecal load. For total phosphorus, load reductions are necessary on Vaughn's Branch downstream of Picadome Golf Course (W04 and W07), Spring Branch (W10), and Big Elm Tributary (W11) due in part to increased loading of wet particulate-bound phosphorus. Reduction of stream erosion and increased filtration of storm flows will aid in reducing the phosphorus levels in priority areas. Reductions of suspended sediments on Vaughn's Branch near the mouth (W04), Spring Branch (W10), and Wolf Run between Faircrest Drive and Lafayette Drive (W09) require reductions in storm loadings. Reduction of the erosive flow levels, restoration of eroded banks, and filtration of stormwater runoff will aid in achieving these target loads.

TABLE 30 – PERCENTAGE ANNUAL LOADING REDUCTION BY SITE

Parameter	% Reduction											
	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12
E. coli – 130 CFU/100mLs	99.6	96.5	99.8	99.7	93.4	96.8	99.3	98.7	99.8	99.7	99.6	95.8
E. coli – 240 CFU/100mLs	99.3	93.6	99.7	99.4	87.9	94.2	98.7	97.5	99.6	99.4	99.3	92.2
Total Nitrogen	-	5	-	-	-	-	-	-	-	-	-	-
Total Phosphorus	-	-	-	49	-	-	18	-	-	42	18	-
Total Suspended Solids	-	-	-	30	-	-	-	-	16	26	-	-

a. *E. coli Loading*

Daily *E. coli* loadings for each event type and site are shown in Figure 6. The average daily load values range from a minimum of 1.49 billion MPN for dry weather at W08 to a maximum of 156 trillion MPN for wet weather at W01. For all sites except W02, the daily load is highest for the wet events, typically near 100 times greater, indicating significant loading is added from sanitary sewer exfiltration as well as runoff sources. Fecal coliform shows a similar pattern of loading as *E. coli* for each site.

FIGURE 6 – DAILY *E. COLI* LOADING BY EVENT TYPE

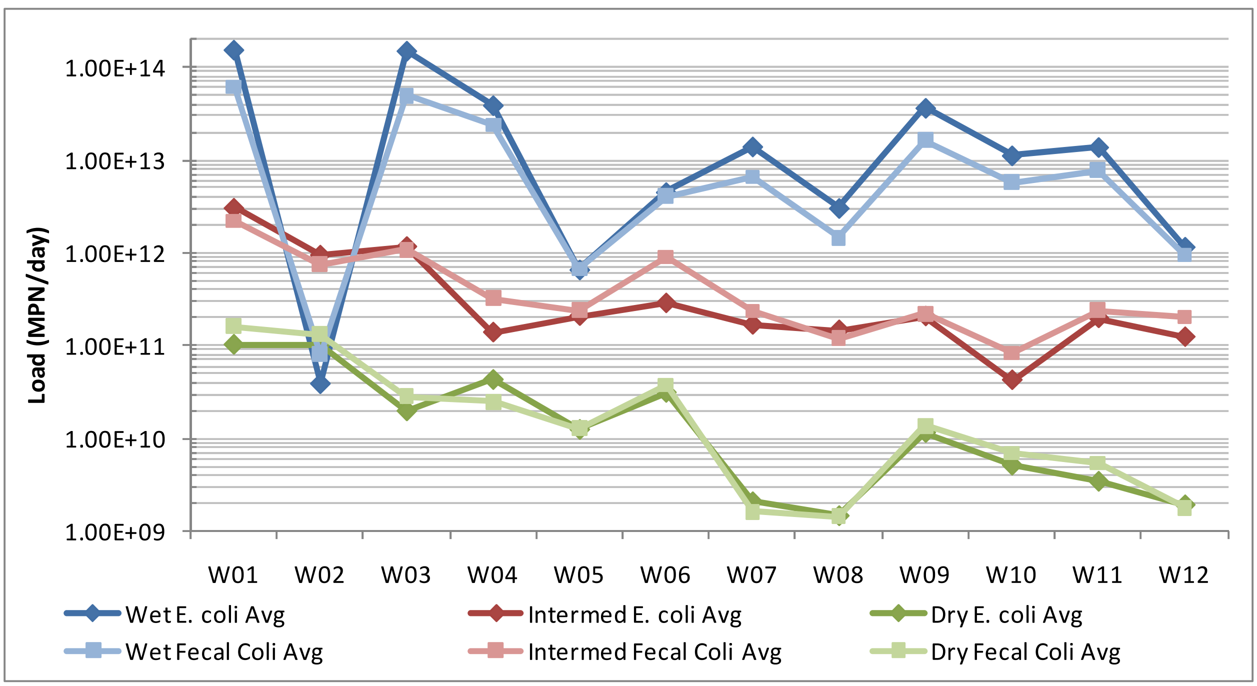


Table 31, page IV-27, indicates the load reductions necessary to achieve the PCR standards of 130 and 240 MPN/100 mLs during all weather conditions. A reduction of over 90 percent is required at all sites in the watershed in order to achieve these results (87.9 percent at W05 is the lowest reduction to achieve the instantaneous standard). For most sites, over 70 percent of the loading comes in wet weather conditions and at some sites (W04, W09, W10), 98 percent of the loading is due to wet weather. The loading for W02 is more evenly distributed across dry and intermediate conditions while W05 has nearly equal loading due to wet and intermediate conditions. Dry weather loading was a very small percentage (less than four percent) of the annual loading at all sites except W02. The large reductions needed to meet targets indicate that supporting recreational use in the Wolf Run Watershed will require significant remediation efforts.

TABLE 31 – *E. COLI* ANNUAL LOAD REDUCTION

Site	Annual Load (trillion CFU/year)	30-day Geometric Mean Target Load* (trillion CFU/year)	Required Reduction (trillion CFU/year)	% Reduction	Instantaneous Standard Target Load* (trillion CFU/year)	Required Reduction (trillion CFU/year)	% Reduction
W01	7317	27.49	7290	99.6%	50.75	7267	99.3%
W02	164	5.69	158	96.5%	10.51	153	93.6%
W03	6840	12.46	6828	99.8%	23.00	6817	99.7%
W04	1750	5.72	1744	99.7%	10.55	1739	99.4%
W05	63.1	4.16	58.9	93.4%	7.68	55.4	87.9%
W06	248	7.77	240	96.8%	14.34	234	94.2%
W07	644	4.45	639	99.3%	8.22	635	98.7%
W08	157	2.10	155	98.7%	3.87	153	97.5%
W09	1645	3.31	1642	99.8%	6.11	1639	99.6%
W10	502	1.65	501	99.7%	3.05	499	99.4%
W11	640	2.29	637	99.6%	4.22	635	99.3%
W12	70.4	2.94	67.5	95.8%	5.42	65.0	92.2%

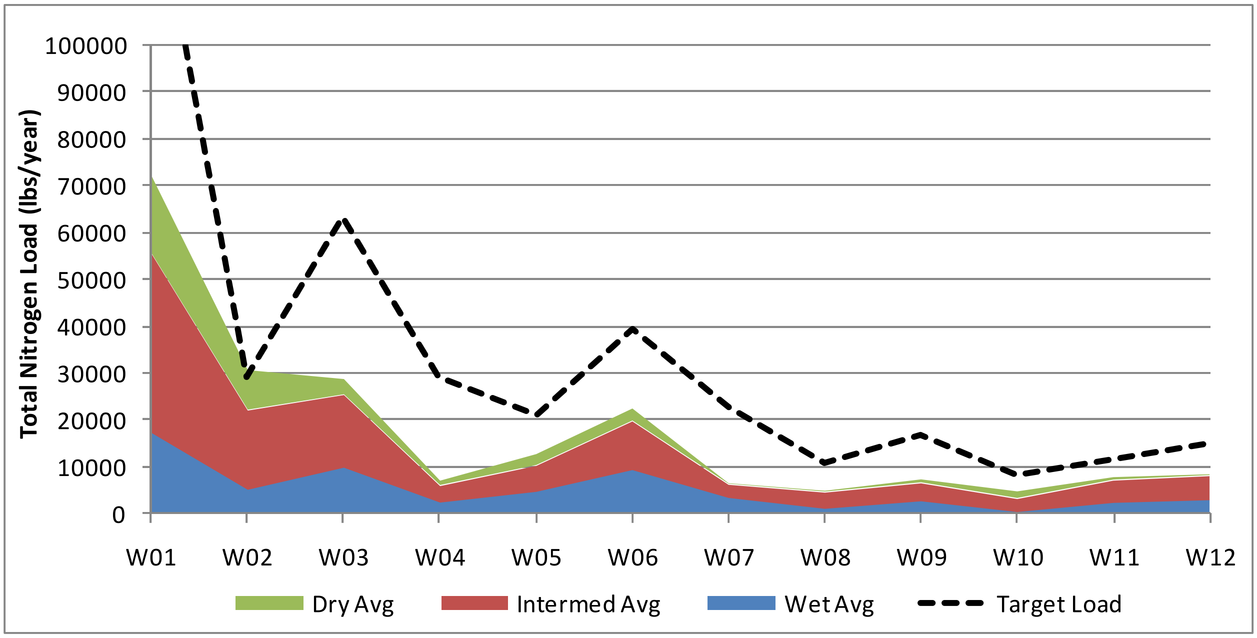
*Targets load based on 130 and 240 CFU/100mLs primary contact recreation standards for *E. coli*, respectively.

b. Nitrogen Loading

Figure 7, page IV-28, indicates the relative contribution to the annual load for each event type at each site. At all sites except W02, the actual annual load is below benchmark load levels. Although concentrations exceeded 3.0 mg/L at dry and intermediate weather conditions for all sites, most sites had very low concentrations (below 1.25 mg/L) during wet weather conditions due to dilution. Wet weather loading was near or slightly above intermediate load amounts at all sites, indicating little additional contribution due to runoff. Intermediate conditions had the greatest load contribution annually for most sites due to the higher flows in conjunction with high concentrations.

As shown in Table 32, page page IV-28, the only site that requires a reduction to reach the target annual loading is W02, which averaged 3.2 mg/L during wet weather events. Removal of 1,600 lbs of nitrogen/year will achieve the target reduction. As W02 is located at Preston's Cave, these load reductions will need to be targeted in the upstream karst basin.

FIGURE 7 – ANNUAL TOTAL NITROGEN LOADING CONTRIBUTIONS BY EVENT TYPE



*Target load based on 3.0 mg/L non-regulatory reference point.

TABLE 32 – TOTAL NITROGEN ANNUAL LOAD REDUCTION

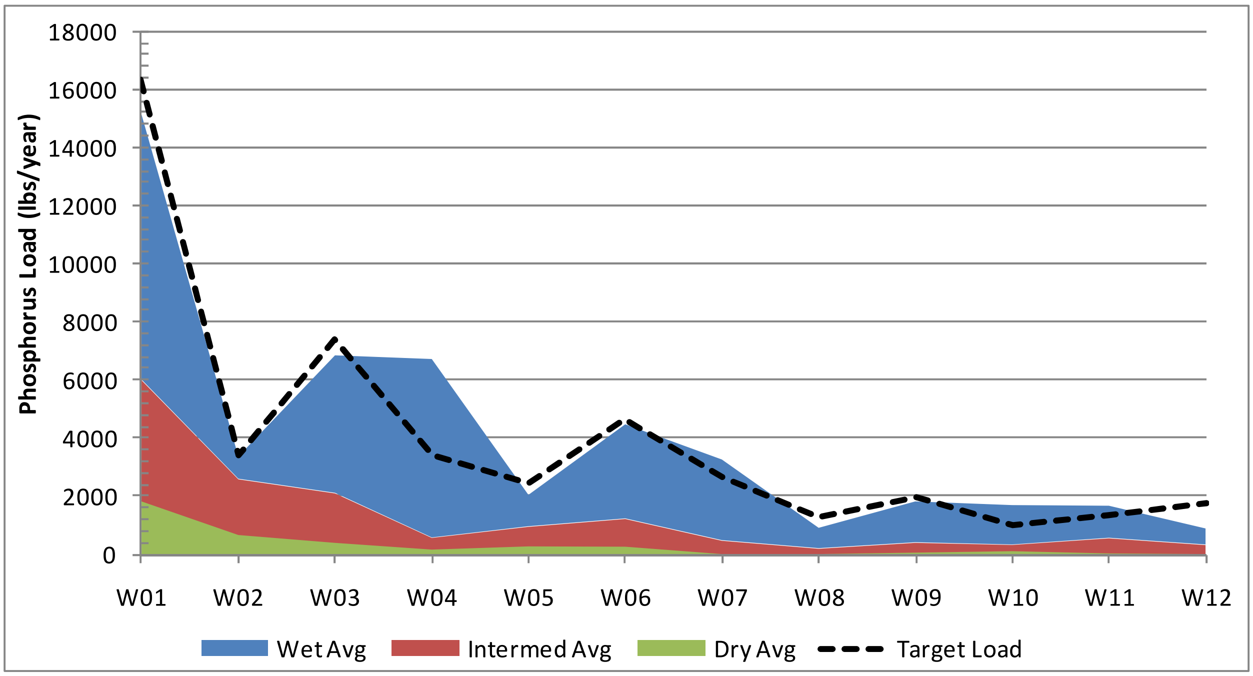
Site	Annual Load	Target Load*	Load Reduction	% Reduction
	(lbs nitrogen as N/year)			
W01	72,100	140,000	-	-
W02	30,600	29,000	1,610	5%
W03	28,700	63,500	-	-
W04	7,020	29,100	-	-
W05	12,700	21,200	-	-
W06	22,400	39,600	-	-
W07	6,460	22,700	-	-
W08	4,850	10,700	-	-
W09	7,290	16,900	-	-
W10	4,710	8,410	-	-
W11	7,750	11,600	-	-
W12	8,380	15,000	-	-

**Target load based on 3.0 mg/L non-regulatory reference point.*

c. Phosphorus Loading

The relative contribution of total phosphorus annual loading for each event type and site are shown in Figure 8. As previously indicated, the total phosphorus concentrations under wet and dry conditions typically average near 0.3 mg/L; wet weather concentrations are higher, particularly for sites W04 and W10, which averaged near 0.8 mg/L. Together with high flow levels, the annual wet weather load contribution was disproportionate to the occurrence frequency, averaging 68 percent of the total load while only occurring on 12 percent of the days.

FIGURE 8 – ANNUAL TOTAL PHOSPHORUS LOADING CONTRIBUTIONS BY EVENT TYPE



*Target load based on 0.35 mg/L non-regulatory reference point.

In order to reach the target loading, load reductions are required at four sites in the watershed, as shown in Table 33, page IV-30. The greatest annual reduction is necessary on Vaughn's Branch, with 3,300 lbs near the mouth (W04); 590 of which are needed upstream of the Pine Meadows Park (W07) primarily from the Picadome Golf Course area. Sizeable annual reductions of 698 lbs in the Spring Branch subwatershed (W10) and 290 lbs from the Big Elm Tributary subwatershed are also required. These reductions should be achieved by erosion reduction and storm event filtration methods.

TABLE 33 – TOTAL PHOSPHORUS ANNUAL LOAD REDUCTION

Site	Annual Load	Target Load*	Load Reduction	% Reduction
	(lbs phosphorus as P/year)			
W01	15,100	16,300	-	-
W02	3,350	3,390	-	-
W03	6,830	7,410	-	-
W04	6,700	3,400	3,300	49%
W05	2,030	2,470	-	-
W06	4,450	4,620	-	-
W07	3,240	2,650	590	18%
W08	894	1,250	-	-
W09	1,810	1,970	-	-
W10	1,680	982	698	42%
W11	1,650	1,360	290	18%
W12	874	1,750	-	-

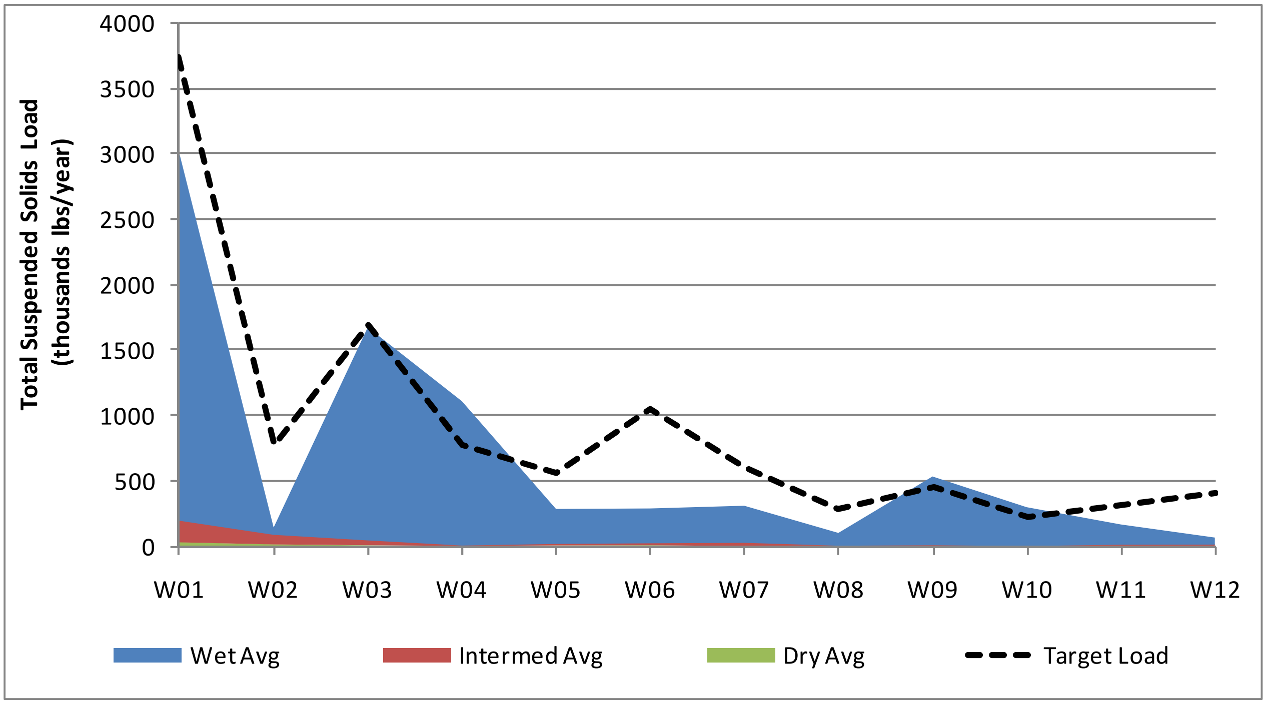
*Target load based on 0.35 mg/L non-regulatory reference point.

d. Suspended Solids

The total suspended solids annual loading and reductions are shown in Figure 9 and Table 34, both of which are located on page IV-31. Dry weather events comprised less than three percent of the total annual load at all sites except W02, which is below Preston's Cave Spring. Wet weather loading averaged 88 percent of the total annual load for all sites as expected due to the higher flows and higher concentrations. Three sites require load reductions to meet target levels. Vaughn's Branch near the mouth (W04) requires a 30 percent reduction of over 300,000 lbs/year. Springs Branch (W10) and Wolf Run between Faircrest Drive and Lafayette Drive (W09) also require annual reductions near 80,000 lbs, which are 26 percent and 16 percent of the total loads, respectively. Reduction of the erosive flow levels, restoration of eroded banks, and filtration of stormwater runoff will aid in achieving these target loads.

According to Kevin Lyne of LFUCG DWQ Compliance and Monitoring Section (Personal Communication October 2012), there are several locations where construction runoff contributed to sediment loading based on notices of violation issued and verbal warnings. Cardinal Valley School (located in W4) and CVS Pharmacy in Spring Branch (W10) were each given several verbal warnings and notices of violation over the monitoring period for issues that contributed to sediment loading in the time between issuance and resolution. The amount of load contribution is unknown, as is other construction site runoff contributions that may have occurred during the monitoring period.

FIGURE 9 – ANNUAL TOTAL SUSPENDED SOLIDS LOADING CONTRIBUTIONS BY EVENT TYPE



Target load based on 80 mg/L non-regulatory reference point.

TABLE 34 – TOTAL SUSPENDED SOLIDS ANNUAL LOAD REDUCTION

Site	Annual Load	Target Load*	Load Reduction	% Reduction
	(lbs/year)			
W01	3,000,000	3,740,000	-	-
W02	148,000	774,000	-	-
W03	1,680,000	1,690,000	-	-
W04	1,110,000	777,000	330,000	30%
W05	290,000	565,000	-	-
W06	294,000	1,060,000	-	-
W07	315,000	605,000	-	-
W08	107,000	285,000	-	-
W09	538,000	450,000	88,000	16%
W10	304,000	224,000	80,000	26%
W11	171,000	311,000	-	-
W12	71,800	399,000	-	-

Target load based on 80 mg/L non-regulatory reference point.

4. Achieving Pollutant Load Reduction Targets

In order to achieve the over 90 percent load reductions required to meet *E. coli* water quality goals, significant remediation of the sanitary sewer system, including private laterals as well as public lines, will be necessary. However, the load reduction achieved by any particular project or line replacement is difficult to project as the bacteria load is dependent upon numerous factors, including the degree of exfiltration, the amount of flow in a particular line, and the concentration of *E. coli*. Because of these factors, an iterative approach of project construction followed with post-construction monitoring will be utilized to determine the reductions achieved for a given project and the need for additional source identification and treatment in the upstream watershed.

For suspended solids, phosphorus, and nitrogen loading, a simple stormwater model (Schueler 1987 as detailed NY DEC 2012) was used to estimate how much individual sources would need to be reduced in order to achieve the calculated pollutant load reductions. Although this method only estimates pollutant loads generated during storm events in urban areas, this is appropriate for the Wolf Run Watershed because it is almost entirely urban and the majority of the loading is attributed to stormwater sources, with the exception of phosphorus for which stormwater sources are a lesser contributor. It is important to consider that these values are estimates intended only to provide a general sense of the magnitude of reductions by source type necessary to achieve the reduction goals.

Under the simple method, the annual load is calculated for each source type based on multiplying the annual runoff by the area and then by the pollutant concentration, converting for unit differences.

The annual runoff volume of the impervious and pervious surfaces was calculated by multiplying the annual rainfall by the fraction of annual events that produce runoff (assumed to be 0.9 as typical) by the runoff coefficient. The annual rainfall value, 45.81 inches was derived by converting the rainfall measured at the KLEX station over the monitoring period (33.76 inches) to an annual basis. The runoff coefficient for pervious surfaces was assumed to be 0.95 and 0.05 for impervious surfaces. Thus, the annual runoff was calculated as 39.2 inches for impervious surfaces and 2.1 inches for pervious surfaces.

Table 35 indicates values that were used for pollutant concentrations for each respective source area. These values are modified from the national values provided in NY DEC 2012, based on KDOW recommendations, to better correlate with loadings observed in the Wolf Run Watershed.

TABLE 35 – POLLUTANT CONCENTRATIONS FROM SOURCE AREAS

Source Area	TSS (mg/L)	TP (mg/L)	TN (mg/L)
Commercial Roof	9	0.20	2.1
Industrial Roof	17	0.20	2.1
Residential Roof	19	0.15	1.5
Driveway	173	0.78	2.1
Parking Lot	228	0.78	1.9
Urban Highway	142	0.45	3.0
Commercial Street	468	0.80	1.4
Residential Street	172	0.80	1.4
Lawns	602	3.00	9.1

A GIS analysis was conducted to determine the amount of area in each subwatershed that was composed of roof (commercial, industrial, or residential), paved driveway, parking (industrial, commercial, and residential), urban highways, commercial streets, residential streets, and lawns (residential, public recreation, and other public facilities). The 2007 comprehensive plan (LFUCG 2007) land use GIS layer was intersected with the impervious surface GIS layer, and then areas within each of these categories were summed to determine the total area of each type within each subwatershed. The acreages are shown in Table 36 and the estimated annual pollutant loadings from stormwater sources summarized in Table 37.

TABLE 36 – ACERAGE OF SOURCE AREAS BY SUBWATERSHED

Land Use	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
Commercial Roof	6.0	15.0	4.5	7.2	12.9	11.9	14.8	68.0	7.8	28.6	33.0	43.1
Industrial Roof	28.5	21.7	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	2.0	2.3
Residential Roof	14.1	21.2	26.5	34.8	85.9	99.2	42.5	40.3	36.9	37.9	44.8	78.3
Paved Driveway	11.0	14.3	18.1	25.2	49.4	54.0	12.9	14.4	18.6	29.6	21.0	43.9
Industrial Parking	47.4	11.2	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	3.8	3.7
C/R Parking	12.4	29.5	17.4	18.9	28.3	36.2	37.8	114.2	12.7	51.3	87.0	89.9
Urban Highway	8.9	5.0	5.3	5.7	19.2	1.2	3.7	10.1	3.0	7.8	6.1	8.4
Commercial Street	16.7	3.3	2.8	2.1	4.4	6.0	3.9	27.5	2.3	2.8	9.7	19.2
Residential Street	17.3	10.9	16.3	20.4	63.1	68.0	27.5	22.3	21.3	25.1	24.4	44.0
Residential Lawns	64.8	82.1	93.9	166.8	460.1	386.1	145.2	103.4	129.4	163.9	184.2	292.4
Public Recreational Lawns	34.46	26.16	3.14	1.75	127.15	26.20	102.16	5.04	0.00	11.06	35.49	3.45
Other Public Facility Lawns	31.60	73.75	17.62	16.92	37.74	27.03	34.05	83.17	11.79	25.46	74.58	6.52

TABLE 37 – ESTIMATED ANNUAL POLLUTANT LOADING FROM STORMWATER SOURCES

Source Area	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
Estimated Annual Total Suspended Solids Load (lbs)												
Industrial and Commercial Roof	4,800	4,500	350	570	1,000	950	1,200	5,400	1,000	2,300	2,900	3,800
Residential Roof and Lawn	21,000	27,000	31,000	53,000	140,000	120,000	48,000	36,000	43,000	52,000	59,000	95,000
Streets and Highways	110,000	37,000	43,000	47,000	140,000	130,000	63,000	160,000	46,000	60,000	85,000	160,000
Parking Lot	120,000	82,000	35,000	38,000	57,000	73,000	76,000	230,000	32,000	100,000	180,000	190,000
Driveway	17,000	22,000	28,000	39,000	76,000	83,000	20,000	22,000	29,000	45,000	32,000	67,000
Other Lawns	19,000	28,000	5,800	5,200	46,000	15,000	38,000	25,000	3,300	10,000	31,000	2,800
Total Load	291,800	200,500	143,150	182,770	460,000	421,950	246,200	478,400	154,300	269,300	389,900	518,600
Sum of Upstream	3,756,870	590,400	1,967,300	907,370	460,000	1,364,150	724,600	478,400	672,900	269,300	389,900	518,600

TABLE 37 - ESTIMATED ANNUAL POLLUTANT LOADING FROM STORMWATER SOURCES, CONTINUED

Source Area	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
Estimated Annual Total Phosphorus Load (lbs)												
Industrial and Commercial Roof	61	65	8	13	23	21	26	120	18	51	62	80
Residential Roof and Lawn	109	143	166	279	757	671	259	198	230	279	317	513
Streets and Highways	277	121	156	182	554	529	237	393	179	229	266	481
Parking Lot	413	281	120	131	196	250	261	789	109	354	627	647
Driveway	76	99	125	174	341	373	89	100	129	205	145	303
Other Lawns	92	140	29	26	230	74	190	123	16	51	154	14
Total Load	1,029	848	604	805	2,101	1,918	1,063	1,723	682	1,169	1,570	2,038
Sum of Upstream	15,550	2,419	8,512	3,591	2,101	5,807	2,786	1,723	2,720	1,169	1,570	2,038
Estimated Annual Total Nitrogen Load (lbs)												
Industrial and Commercial Roof	642	682	83	133	241	221	275	1,264	192	532	651	843
Residential Roof and Lawn	462	630	749	1,170	3,092	2,953	1,179	974	1,039	1,198	1,376	2,279
Streets and Highways	659	308	377	430	1,345	949	486	885	373	553	585	1,006
Parking Lot	1,007	685	292	319	477	609	637	1,921	267	863	1,527	1,575
Driveway	205	266	336	468	918	1,004	240	268	346	551	390	816
Other Lawns	280	424	88	79	699	226	577	374	50	155	467	42
Total Load	3,254	2,995	1,926	2,598	6,772	5,963	3,395	5,687	2,267	3,852	4,995	6,562
Sum of Upstream	50,265	7,990	27,340	11,680	6,772	18,643	9,082	5,687	8,829	3,852	4,995	6,562

Based on these estimates, the restoration activities should be targeted towards capturing and reducing the pollutant load from residential roof and lawns, parking lots, and streets and highways since these represent the largest stormwater sources of total suspended solids, phosphorus, and nitrogen. In order to achieve the reduction goals summarized in Tables 32 through 34, one reduction scenario is proposed in Table 38, page IV-35. Although these reductions would not meet the phosphorus reduction targets according to the model, stormwater comprised a lesser portion of the overall phosphorus loading and the model predicts only loading due to stormwater, so the actual reductions may be greater. The nitrogen load reduction required for the Preston's Cave/McConnell Springs karst basin drainage is addressed through reductions in Vaughn's Branch, Big Elm Tributary, and Upper Wolf Run.

TABLE 38 – REDUCTION OF STORMWATER SOURCE LOADS TO ACHIEVE POLLUTANT REDUCTION TARGETS

Source Area	Lower Wolf Run (W1,W3)	Preston's Cave / McConnell Springs (W2)	Cardinal Run / Garden-side Trib (W5)	Middle Wolf Run (W6)	Vaughn's Branch (W4, W7, W8)	Spring Branch (W10)	Big Elm Tributary (W11)	Upper Wolf Run (W9,W12)
Residential Roofs and Lawns	0%	0%	0%	0%	30% TSS, TP, TN	35% TSS, TP	25% TP, TN	25% TSS, TN
Streets	0%	0%	0%	0%	30% TSS, TP, TN	35% TSS, TP	25% TP, TN	15% TSS, TN
Parking Lots	0%	0%	0%	0%	20% TSS, TP, TN	50% TSS, TP	25% TP, TN	25% TSS, TN