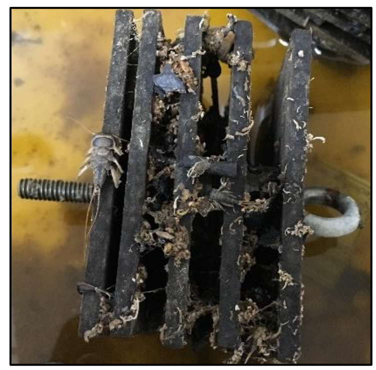
Preliminary ecological assessment of the Green and Nolin rivers in Mammoth Cave National Park, Kentucky, following the removal of lock and dam #6



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Executive Summary

It is estimated that there are nearly 90,000 man-made dams within the waterways of the United States, with approximately 1,100 dams in Kentucky. While dams provide many benefits to society, they have a profound negative impact on natural aquatic ecosystems and some may pose a risk to public safety. When the 110-year-old lock and dam #6 (L&D 6) on the Green River near Brownsville, Kentucky, breached in November 2016, a partnership between the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, National Park Service, Kentucky State Nature Preserves (KSNP), and other partners was established to oversee and evaluate the removal of the dam during spring 2017. The objectives of the dam removal were to eliminate the public safety hazards, restore the immediate section of the Green River within Mammoth Cave Nation Park (MCNP) to more natural hydrological conditions, and to document the environmental response and recovery.

The Green River in MCNP is considered a global bioreserve and is one of the most diverse river drainages in Kentucky for fish, crayfish, freshwater mussels, and other aquatic invertebrates. Therefore, the potential recovery of the aquatic fauna is great. Documenting and monitoring the recovery is critical for optimally informed nature resource management. During the summer and fall of 2017, KSNPC staff conducted baseline surveys to assess the current physical and biological conditions from approximately 24 river kilometers (15 miles) upstream within the Green and Nolin rivers that were formerly impacted by L&D 6.

The initial surveys indicated that the free flowing hydrological conditions of the Green River expanded approximately 16 river km downstream following dam removal (Figure 1). However, the presence of lock and dam #5 near Glenmore, Kentucky, still impounded the Green and Nolin rivers upstream to Crump Island and Second Creek, respectively. The instream habitat within the impounded section was predominantly comprised of mud and sand (84%), while the substrate composition within the free flowing section was more variable and evenly mixed among mud and sand (47%), and gravel and pebble (39%). The riparian zone along both hydrological sections exhibited numerous areas of extensive bank erosion and collapse, exposing large areas of bare soil and canopy loss. An estimated 60% of the banks within the impounded section had experienced bank failure, while the free flowing section experienced approximately 15%.

Plant composition and richness along the riparian zone was relatively similar among the hydrological sections (Table 1). The invasive herbaceous species, oriental lady's thumb (*Persicaria longiseta*) and Japanese stiltgrass (*Microstegium vimineum*), were common and are indicative of disturbed habitats. The macroinvertebrate fauna had greater richness in the free flowing section, but the overall composition of the fauna was largely comprised of the same three to five taxa. This indicates that even though different hydrological conditions currently exist, the fauna still represents an assemblage of the historical hydrological conditions. Twenty-seven species of mussels were encountered, including the federally endangered species, fanshell (*Cyprogenia stegaria*) and sheepnose (*Plethobasus cyphyus*). Mussel richness and abundance were greatest within flowing habitats (i.e., riffle and run). The fish fauna was diverse with 58 native species. The free flowing section of the river had the greatest richness and abundances, however, low abundance of benthic species (bottom dwelling) within this section suggest that the fish fauna is more indicative of the historical impounded conditions.

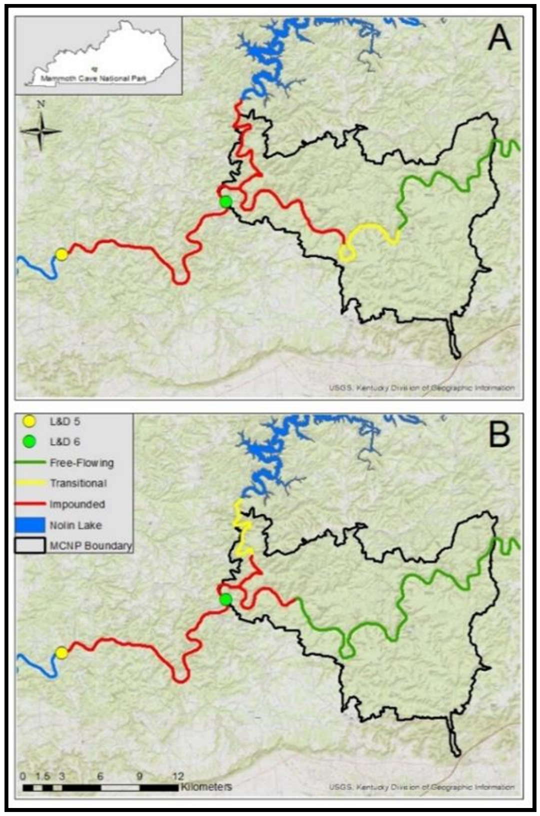

Figure 1. Historical (A) and current (B) hydrology of the Green and Nolin rivers near MCNP.

Table 1. Mean taxa richness of biological groups within hydrological and habitat categories.

Biological groups (number of sites per category, respectively)	Hydrology		
	Impounded	Flowing	
Vegetation (9, 6)	10.6	10.5	
Macroinvertebrates (3, 2)	29.7	40.0	
Fish (3, 2)	20.0	44.0	
	Habitat type		
	Impounded	Flowing	Pool
Mussels (3, 14, 10)	1.3	9.3	2.3

Overall, the removal of lock and dam #6 decreased the permanent and seasonal impoundment of the Green River by 16 river km. However, the presence of lock and dam #5 still impounds the lower Green and Nolin rivers within MCNP. It is hypothesized that the flora and fauna will recover over time as the river corridor stabilizes and the smaller substrate particles are distributed further downstream. The rate and degree of recovery will vary among biological groups and within the different hydrological regimes. It is recommended that monitoring of the vegetation, macroinvertebrates, fish, and habitats continue on an annual basis for the next five years, while mussels be monitored at an interval of every five years for the next twenty years. Lastly, the monitoring data should be thoroughly analyzed to fully understand and assess the recovery of the river and its biological and physical components, with adaptive management implemented to amend for the dynamic environment.

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Introduction

It is estimated that there are nearly 90,000 man-made dams that occur within the waterways of the United States, with approximately 1,100 dams within Kentucky (Bellmore et al. 2017). Although dams have provided benefits in navigation, flood control, and recreation, the presence of dams on the natural aquatic fauna, water quality, and the hydrology have been profoundly negative. Dams drastically alter the upstream habitat from cool, shallow, highly oxygenated flowing water to warmer, deeper, and less oxygenated standing water, which has been shown to decrease species richness and homogenize the local fauna (e.g., Guenther and Spacie 2006; Hayes et al. 2006; Winston et al. 1991). In particular, dams have decimated freshwater mussels, with dozens of species (e.g., *Epioblasma* spp.) going extinct (Haag 2012). In recent decades, however, the removal of dams has increased, because of liability and safety concerns, as well as a shift in policy toward biodiversity and habitat restoration.

In November 2016, lock and dam #6 (L&D 6) on the Green River near Brownsville, Kentucky, experienced increased structural malfunction. The dam was considered for removal prior to the recent breach because it was in disrepair for many decades, but its removal became imminent as safety concerns increased. A partnership between the U.S. Army Corps of Engineers (USACOE), U.S. Fish and Wildlife Service (USFWS), National Park Service (NPS), The Nature Conservancy (TNC), Kentucky Department of Fish and Wildlife Resource (KDFWR), and Kentucky Waterway Alliance (KWA) was established and the removal of the dam was scheduled for spring 2017. The objectives of the dam removal were to eliminate the safety hazards and to restore the immediate section of the Green River to more natural flow conditions.

The science of dam removal and our understanding of the recovery of stream habitats and the local fauna is sparse. Approximately 1,200 dams have been removed in the United States, but fewer than 10% of the dam removals have been scientifically assessed and published (Bellmore et al. 2017: Foley et al. 2017). In Kentucky, four dam removals have been documented, but no scientific review of the process has been published (Bellmore et al. 2017). The need to understand and document the recovery of stream habitat and the local fauna following dam removal is essential if resource managers are to optimize the benefits of removing dams (Oliver and Grant 2017). This is especially important for the recovery of the Green River and its fauna within Mammoth Cave National Park (MCNP) that were impacted by L&D 6. The Green River is considered a global bioreserve, harboring numerous rare and unique species; and Cicerello and Hannan (1991) suggested that the freshwater fauna within MCNP is the most diverse among the national park systems. Therefore, the potential recovery and range expansion of rare species - particularly fishes, crayfishes, and mollusks - are great. To properly document and understand the recovery in its entirety it is critical to develop a monitoring program that obtains data that incorporates the river conditions and local fauna prior, immediately after, and long-term following the removal of a dam. Most dam removal projects fail in this endeavor, which has created a gap in our understanding of dam removals and the impact and potential benefits on the local fauna after the dams are gone (Bellmore et. al 2017).

In summer 2017, USFWS, MCNP, and Kentucky State Nature Preserves Commission (KSNPC) agreed to document the current conditions following the spring 2017 removal of L&D 6 on the Green River. The broad goals were to document the current physical conditions and inventory the riparian zone and aquatic fauna within the portion of Green and Nolin rivers upstream from the former location of L&D 6. No statistical analyses of the data were conducted. Specifically, the primary objectives were to:

1. Document the riparian zone conditions
2. Document the macroinvertebrate fauna
3. Document the freshwater mussel fauna
4. Document the fish fauna
5. Document the in-stream habitat conditions
6. Provide management recommendations

Methods

Study Area

The approximate 20 river kilometers of the Green River upstream of the former location of L&D 6 to the pool above Sand Cave Island (latitude/longitude: 37.17948/-86.15418) and approximately three river kilometers upstream on the Nolin River from the Green River confluence was the focus of the study (Figure 1). All data collected were within the MCNP boundaries. The Green River enters MCNP from the east and flows westward approximately 40 km before leaving MCNP just upstream of L&D 6. Extensive karst topography primarily exists within the southern portion of MCNP and the only major tributary that joins the Green River is the Nolin River from the north. Most other sources of water that drain into the Green River come from underground streams and springs that percolate through the limestone. It is estimated that nearly 80 subsurface or surface springs drain into the Green River within MCNP (Pond 1996).

The former location of L&D 6 on the Green River (37.20641/-86.26083) was approximately three km downstream of the Nolin River confluence in Edmonson County, Kentucky. According to National Park

Service (1983) the structures were built in 1906 and 1907. Navigation was the primary purpose for the dam, but its services were eventually terminated by the USACOE (1981). Lock and dam 6 remained structurally, but its condition was often in disrepair and leaked until its removal in spring 2017.

Historically, based on the impoundment created by L&D 6, sections of the Green River that meandered through MCNP were designated into three hydrological categories: impounded, transitional, or free flowing (Cicerello and Hannan 1990; Pond 1996). Impounded was defined as river continuously impacted by L&D 6, where flow was laminar and minimal and depth the greatest, free flowing was defined as river that was not directly impacted from L&D 6 and contained riffle, run, and pool habitat sequences, and transitional was defined as river that would experience impounded conditions and free flowing conditions, with respect to seasonal changes. The extent of these categories varied based on seasonal water level changes and the status of the dam condition. When the dam was in good condition and during normal high-water the impounded section would extend upstream to the Green River Ferry and Cave Island vicinity (this marked the downstream extent of free flowing conditions). During extreme drought conditions and the dam being in disrepair, the water would rescind and only impound to Boardcut Island (downstream extent of transitional conditions). Under typical base flow conditions and with the dam in disrepair, the Green River would be impounded to the pool upstream of Sand Cave Island (Cicerello and Hannan 1991; Pond 1996). The impact of L&D 6 on the Nolin River was extensive and would reach to the Nolin River Dam during high water. This section of the Nolin River experienced only impounded or transitional conditions based on seasonal changes and the discharge from Nolin River reservoir.

The extent of the historical hydrological conditions has shifted downstream following the breach of November 2016 and the subsequent dam removal in spring 2017. Currently, the Green River is no longer impacted from L&D 6, but the influence from lock and dam 5 (L&D 5, 37.16867/-86.40328) still remains. The impounded river from L&D 5 extends to the downstream pool of Crump Island on the Green River and upstream on the Nolin River past Second Creek. It is currently unknown if the extent of pool 5 extends upstream of Crump Island during high water. The Green River upstream of Crump Island exhibited free flowing conditions during summer and fall 2017. The current study categorized sites within the Nolin River and Green River, from the former location of L&D 6 upstream to Crump Island as impounded (currently by L&D 5), and sites within the Green River, upstream of Crump Island, as free flowing.

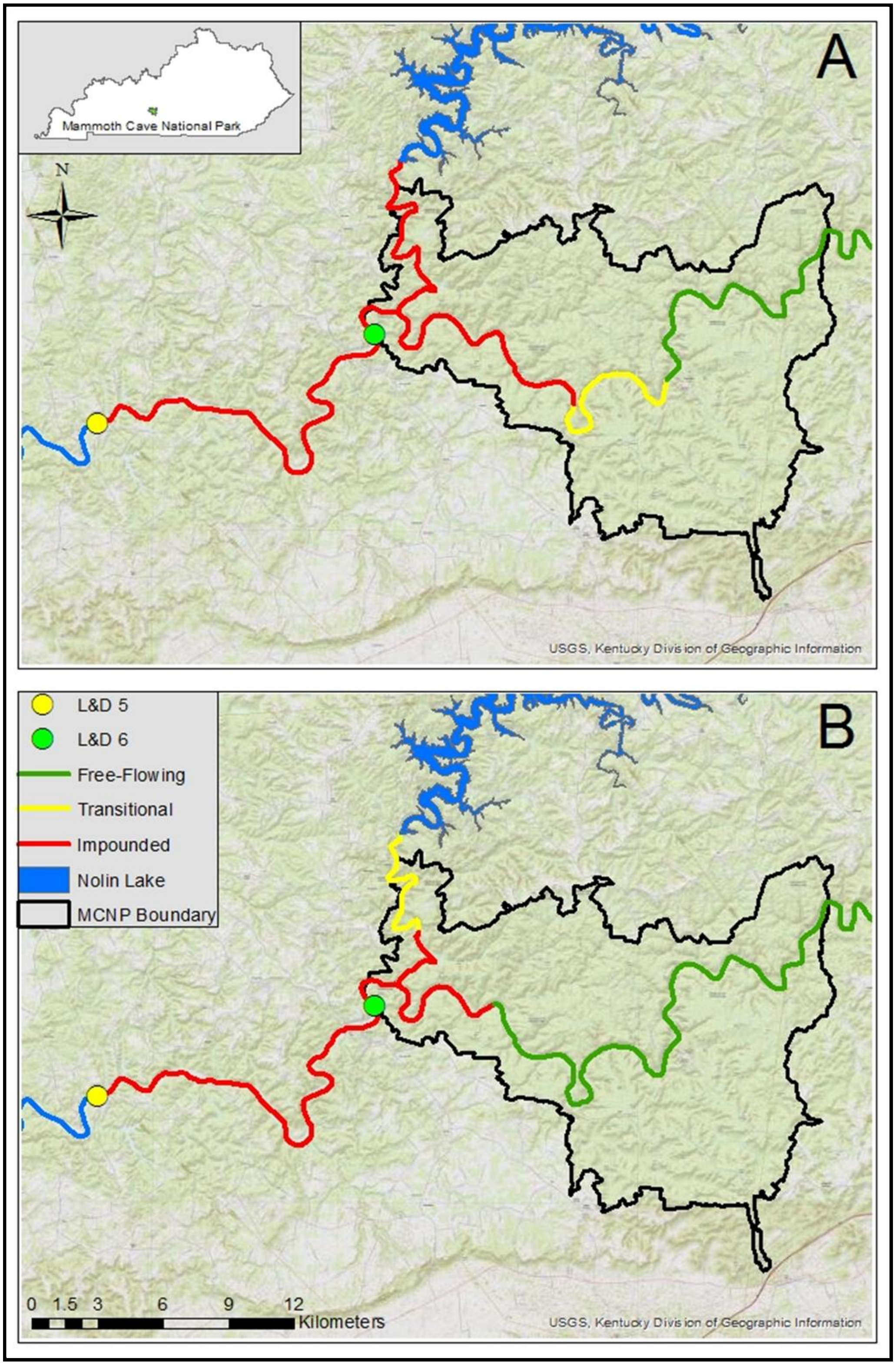

Figure 1. Historical (A) and current (B) hydrology of the Green and Nolin rivers near Mammoth Cave National Park (MCNP).

Riparian Zone

The goal of assessing the riparian zone was to assess the current physical conditions and document the floral diversity and relative species abundances along the Green and Nolin rivers. A systematic approach was taken to obtain adequate coverage and account for the potential variability of the riparian zone along the 24 river kilometers within the study area. Thirteen Green River sites and two Nolin River sites were established, with the first Green River site (GR1) approximately 0.8 kilometers upstream from L&D 6 and each subsequent site approximately 1.6 river kilometers upstream from the previous site (Figure 2). To reduce field time only one bank was surveyed for vegetation at a site, and determination of which bank, downstream facing left bank or downstream facing right bank, was done randomly prior to site visit to eliminate bias. At a site, a 2m x 12m plot was developed to obtain canopy closure, shrub cover, woody stem counts, mature tree identification and size, dominant species and % cover data. In addition, two (occasional three, if deemed necessary by lead investigator) quarter-meter quadrats were randomly placed within the larger plot at a site for species identification and % cover. Lastly, photo points, wetted stream width, field geographical coordinates were obtained at a site (Appendix A).

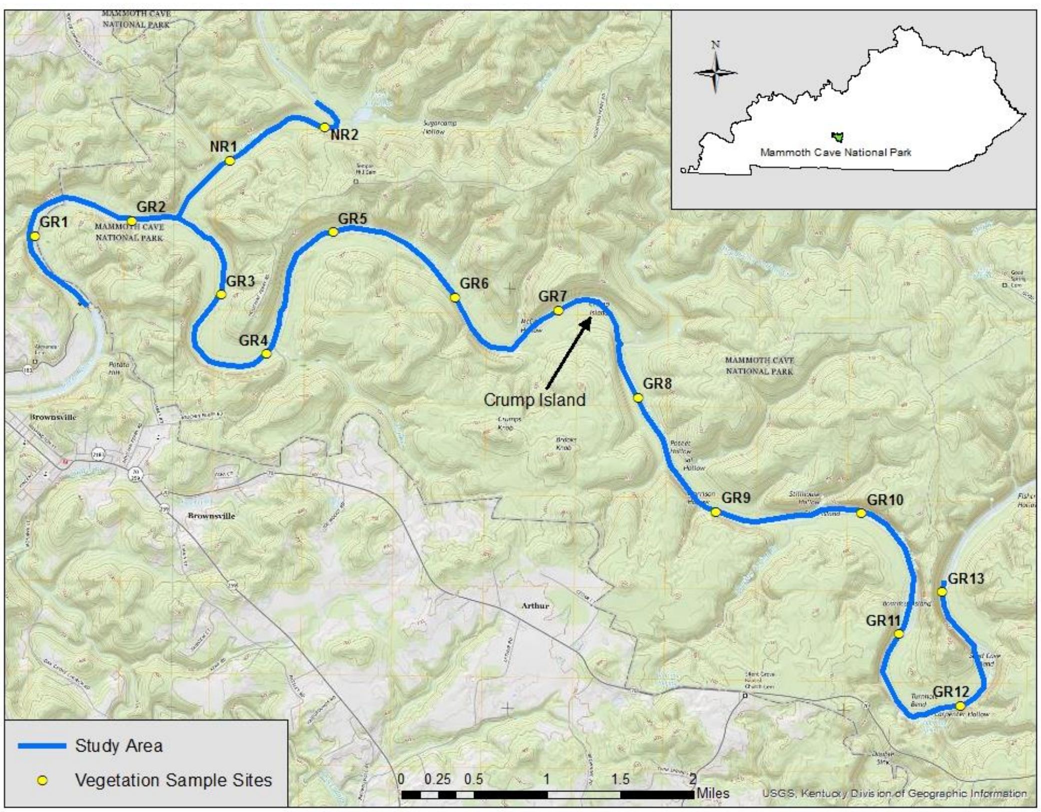

Figure 2. Riparian zone sites along the Green and Nolin rivers, MCNP (2017).

Data collection was conducted during a late summer index period, August 16 – September 21, 2017 (Table 1). A short time frame for obtaining the vegetation data is important to minimize any growth variation that may occur between sites. It is also important to make these data collections when the water levels are relatively equal. Large fluctuations in water levels can skew the perspective of the photo points. Water level data at the Green River Ferry was provided by MCNP staff (Table 2). Future riparian zone sampling should target these relative water levels.

Table 1. Vegetation site locations and survey date.

Stream	Site	Latitude	Longitude	Date surveyed
Green River	GR1	37.211336	-86.267228	16-Aug-17
Green River	GR2	37.214908	-86.255235	16-Aug-17
Green River	GR3	37.207659	-86.244089	16-Aug-17
Green River	GR4	37.201786	-86.238470	17-Aug-17
Green River	GR5	37.213895	-86.023026	17-Aug-17
Green River	GR6	37.207498	-86.215082	21-Aug-17
Green River	GR7	37.206275	-86.202175	19-Aug-17
Green River	GR8	37.197640	-86.192253	19-Aug-17
Green River	GR9	37.186350	-86.182518	19-Aug-17
Green River	GR10	37.186247	-86.164570	19-Aug-17
Green River	GR11	37.174300	-86.159716	19-Aug-17
Green River	GR12	37.167208	-86.152122	19-Aug-17
Green River	GR13	37.178498	-86.154448	19-Aug-17
Nolin River	NR1	37.220987	-86.243089	20-Aug-17
Nolin River	NR2	37.224317	-86.231333	20-Aug-17

Sites GR1 thru GR5 were surveyed during August and accessed with a kayak and canoe. Sites GR6 thru GR13 and NR1 and NR2 were surveyed during September, GR6 thru GR13 were accessed with a 16 ft jon boat with a jet engine motor. Geographical coordinates were obtained for each site (center stream site point) prior to field sampling using ArcMap software ver. 10.3 (Environmental Systems Research Institute, ESRI). Navigation to the specific geographical coordinates of a site was assisted with a digital map (live navigation) using an iPad mini 4 Bluetooth-linked to a Bad Elf GPS PRO+. The mapping software-application used for this was ESRI's "Collector".

Table 2. Green River Ferry (MCNP) river gauge (2017).

Month	Date	Time	Gauge Level (ft)
August	16	6:04	0.1
August	16	13:54	0.0
August	17	7:09	-0.3
September	19	5:44	0.7
September	19	14:07	0.6
September	20	5:46	0.5
September	21	5:55	0.4
September	21	14:01	0.35

Whether using canoe or motorboat, an anchor was essential to holding the boat in one relative location in the middle of the stream (Figure 3). Best accuracy was accomplished by dropping the anchor into the water several meters upstream of the point, with the flow pulling the boat downstream from the anchor (this holds the boat several meters downstream from where the anchor grabs into the stream bottom). A margin of error less than 20 meters was acceptable for recording center-stream location (the set of points created in office were the locations used to navigate). If establishing the same plot is deemed important for long-term results, the points collected/installed can be used as the Bad Elf GPS PRO+ (refer to as GPS Pro) is capable of collecting points accurate to 8 feet (2.5 m). However, accuracy attained during sampling of center-stream points were mostly less than 20 feet but not less than 10 feet (multiple points were collected and averaged together). Accuracy information attained from GPS Pro was written on datasheets. Once points were collected in the center of stream, wetted stream width and two photo points of each bank were collected using a SIG Sauer rangefinder (model KILO2000) and a Panasonic Lumix camera (model DMC-TS30), respectively. The wetted width was obtained by aiming the SIG Sauer rangefinder at the water's edge of both banks and adding the two values together for the total wetted width of stream. Several aims at each bank were taken and then compared to strengthen confidence in the readings and eliminate the occasional error in the readings. Photos were taken by kneeling in the motorboat or simply sitting in the canoe, at a collection height of approximately 3 feet/1 m above the water (Figure 4A and 4B).

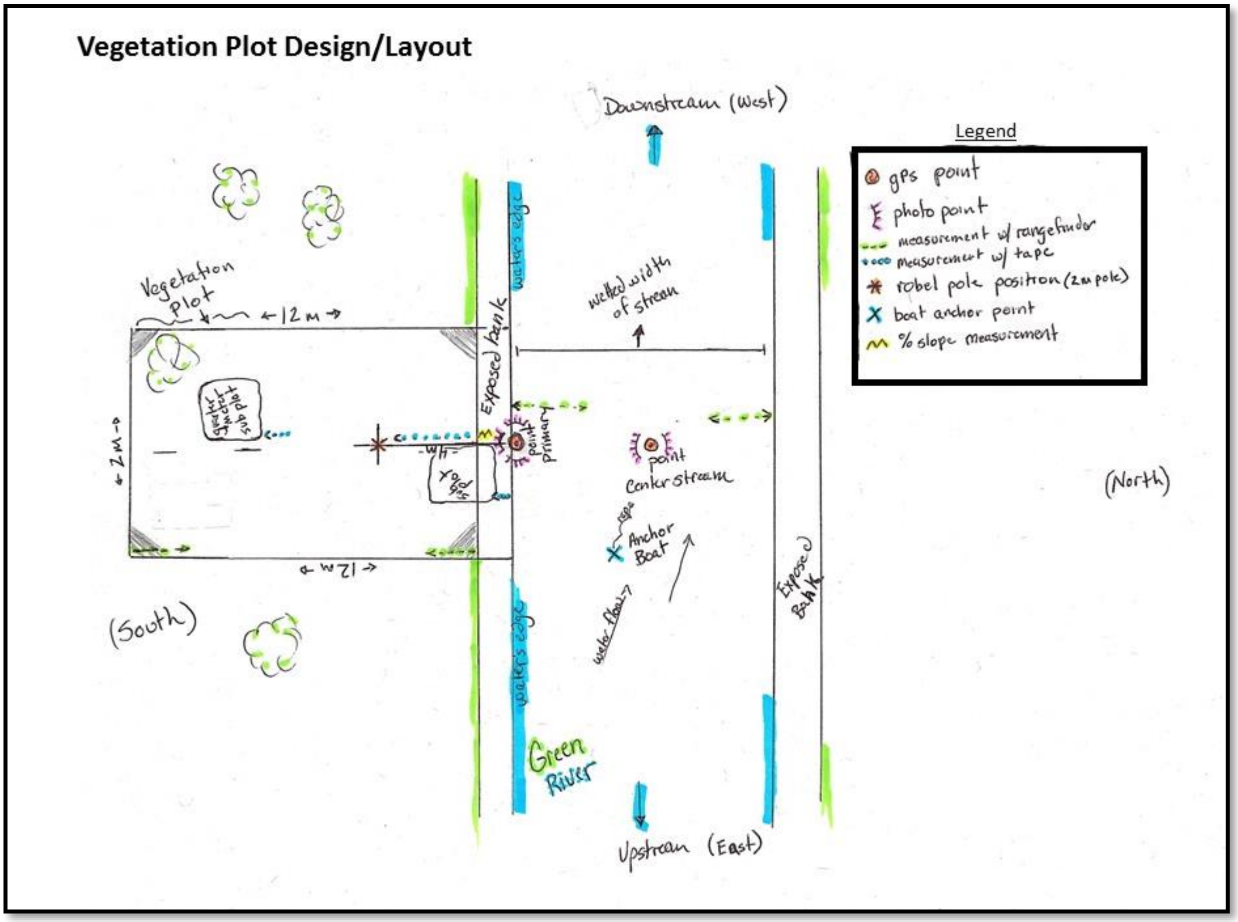

Figure 3. Vegetation site diagram.

A field crew of at least three members were used to established one 2m x 12m bank vegetation plot at a site. The specific bank (left bank or right bank) surveyed was determined randomly prior to the field visit. The vegetation plot at a site was perpendicular from the center stream location and the specific location was determined by visually locating a spot along the bank and holding it to memory until the watercraft could be maneuvered to a point that is right or left of the targeted spot, which allowed the field crew to operate without hindrance from the watercraft. At the plot, a crew member would stand on the bank at the water's edge and obtain the plot reference point with an iPad mini 4 linked to a Bad Elf GPS PRO+ using Collector. In addition, three photo points at eye level and oriented as bank-facing, upstream, and downstream were taken at the plot (Figure 4 C-E). A general rule in collecting upstream and downstream photo points was to have 1/3 water and 2/3 land visible in the photo, with a level horizon (Figure 4D and E). The presence of the watercraft in the upstream or downstream photo points was not desirable, but was hard to avoid. For the bank-facing photo, a 2-meter tall robel pole was included 4 meters from the plot reference point (this is for measuring structure/the shrub zone). It was efficient to have a crew member hold the robel pole while another crew member obtained the photo point. This was acceptable in 2017 due to minimal vegetation growing at 4 m (measured with a meter tape), but may need modification with changing vegetation growth (a temporary stake could be installed to hold the pole and let the collector exit the data view). It is important to note that the primary investigator was approximately 6 ft in height and if future collectors are shorter or taller by 3 inches slight adjustment might be needed for photo points. Associated azimuths were collected for the upstream and downstream photo points by matching the camera view angle with a compass azimuth (iPad mini was used: generic compass app). The plot boundary, especially the longest extent (12m) from the water's edge was checked using the rangefinder. The "distance to top of bank" measurement was also recorded in this area of the plot with the rangefinder; if the top of bank was beyond 12 meters, 12 m+ was often recorded. However, if the top of bank was easy to maneuver, beyond the 12 meters or if it was easy to see, a rangefinder was used and the measured distance recorded. The 2-meter plot boundary width was determined using a meter-tape/center line as reference and holding out the robel pole.

Identifying vegetation within the plots was the most advanced skill needed to complete the project. Once plants were identified, vegetation was recorded mostly as a percent cover, such as canopy closure, general shrub cover, five dominant species, individual shrub species cover, and the two quarter-meter sub-plots/quadrats (Appendix A). Specific stem counts were recorded for all woody species taller than dbh (diameter at breast height: 1.3 m); this included trees and shrubs but excluded woody vines (woody vines were recorded in shrub species percent cover and as a part of the dominant five species, when applicable). For all plots, stem counts per category were less than ten stems per plot, but such low counts are expected to change. When recording the dominant five species in the plot, a sixth species was deemed acceptable when percent cover matched that of the fifth/last species, i.e. a clear "dominant fifth" was indiscernible. In addition, vegetation data was obtained from two, randomly placed, quarter-meter square quadrats. A third quadrat was optional if one of the two quadrats occurred within the non-vegetated bank zone. Location of the third quadrat was determined by the botanist/vegetation ecologist within the vegetated zone of the plot, often choosing an area characteristic of the plot or with vegetation different from the first quadrat.

A. GR5 Center stream - North #77 (Plotside)

B. GR5 Center stream - South #76

C: GR5 Primary-bank-facing #81

D: GR5 Primary-downstream #80

E: GR5 Primary-upstream #79

F: Brice Leech, MCNP staff: site transport

Figure 4. Example of photo points at site GR5 (A-E); and motorboat transport (F). All photos by Brian Yahn (August 17, 2017).

In future studies, if the woody stem count significantly increases during the monitoring period of the dam removal then the estimated stem count classes should be utilized for the “Sapling 1” and “Sapling 2”, and potentially the “Small Tree” categories (i.e., stem counts may change from a few to hundreds and the classes will help account for this). It is important to document that woody stems are increasing and at a certain density, but a specific count is not necessary; this “counting in bunches” design increases sampling efficiency. Perhaps a seedling % cover parameter is needed in future sampling, (KSNPC is confident that everything sampled in 2017 had a seedling density less than 15% cover). And further, defining the term “seedling” as any woody tree or “newly sprouted” shrub that is shorter than dbh/1.3 m. Note: Any established/mature shrub (or tree for that matter) under 1.3 m would be recorded in individual shrub species cover and not seedling % cover because the target for the seedling category is for recruitment, i.e. germinating stems. Also, recording vegetation coverage on the robel pole may prove beneficial for future monitoring. 2017 showed minimal growth along the robel pole, 4 m from the water’s edge (Figure 4C), but that has a high potential to change and would be readily available for adding to the sampling protocol.

Macroinvertebrates

Five sites were selected to characterize the macroinvertebrate fauna (Figure 5). Two sites were selected within the impounded section of the Green River, below Crump Island, and two sites within the free flowing section (formally transitional) of the Green River, above Crump Island (Table 3). One site within the impounded section of the Nolin River was established. The sites were approximately 150 m in length and were considered typical locations that represented the broader reaches of river. Sampling techniques at each of the sites were standardized as much as possible based on the available, workable habitat. Overall, the goal was to capture a representative macroinvertebrate community at each site to establish baseline diversity and relative abundance data.

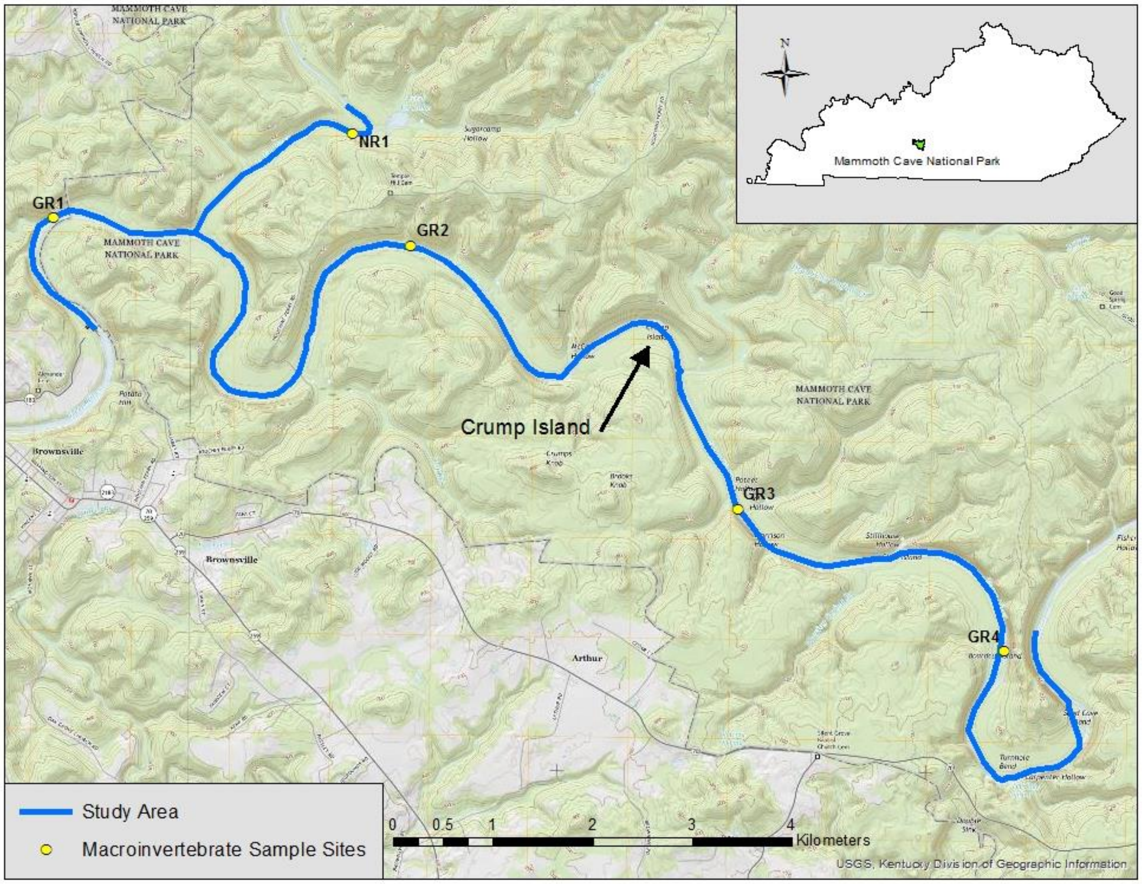

Figure 5. Macroinvertebrate site locations.

At each site, if available, qualitative samples of approximately 3 linear meters of 'weathered' wood (> 0.03 m in diameter), 5 rocks (b-axis > 64 mm), and 5 dip net (< 1000 µm mesh size) sweeps into depositional areas were made, as well as a general search among other unique microhabitats (e.g., mid-channel snags). Quantitative sampling at each site consisted of deploying Hester Dendy (HD) artificial samplers. The HD samplers were attached to cinder blocks, which were placed in the erosional zone of the channel at each of the sites. Each cinder block had four HD units attached to them. Each HD unit was comprised of five 7.62 x 7.62 cm hardboard plates that were variably spaced apart (Figure 6). The total HD surface area for each site was 0.23 m^2. A buoy was attached to each cinder block for retrieval. The HD units were left in the river for macroinvertebrate colonization between 43-51 days. Semi-quantitative sampling was done only at the two free flowing sites. Four 0.25 m kick net (< 500 µm mesh size) samples were taken in riffle habitat at the free flowing sites.

Figure 6. Hester Dendy unit after colonization period showing variable spacing between the hardboard plates.

Table 3. Macroinvertebrate site locations, date collected, and Hester Dendy duration.

Stream	Site	Latitude	Longitude	Date Collected	Hester Dendy colonization (days)
Green River	GR1	37.21655	-86.26556	27-Sept-17	43
Green River	GR2	37.21420	-86.22507	27-Sept-17	45
Green River	GR3	37.19047	-86.18797	21-Sept-17	45
Green River	GR4	31.17772	-86.15781	21-Sept-17	45
Nolin River	NR1	37.22433	-86.23169	21-Sept-17	51

Note: All Hester Dendy samplers were deployed on September 11, 2017.

Sample processing in the field consisted of using forceps, pans, squirt bottles, buckets, and sieves (500 and 1000 µm) to separate and condense material. The remaining material was placed in containers with 95% ethanol, labeled, and taken to the laboratory for further processing. Laboratory processing consisted of using microscopes, sieves (500 µm), pans, and forceps to sort and identify any macroinvertebrate specimens from debris. Macroinvertebrates were identified to the taxonomic family level and enumerated. Laboratory processing and specimen identification was conducted by Natalia Maass at Eastern Kentucky University (EKU) under the supervision of Dr. Amy Braccia, who confirmed specimen identification. Initially, the qualitative microhabitat samples were kept separate by habitat type, but are reported as a qualitative composite at a site. Quantitative and semi-quantitative samples are reported as abundances for each site.

Freshwater Mussels

The goals of the mussel surveys were to generate baseline diversity and relative abundance data according to habitat type. The section of Green River below Crump Island and all of the Nolin River were considered impounded, because of the existing influence from L&D 5. The Green River upstream from Crump Island was considered free flowing. Mussel surveys were conducted within both sections, with the majority of surveys conducted within the free flowing section. Habitat within the free flowing section was designated as flowing or pool based on the hydrology. Sites within each habitat type were surveyed for live mussels, with the majority of surveys conducted within flowing habitat (Figure 7). Each survey consisted of searches along three transects that extended bank to bank. The precise site location for each mussel survey was determined randomly using geographical coordinates generated from GIS. The geographical coordinates represented the location of the middle transect (Table 4). The two remaining transects surveyed were 10 meters upstream and 10 meters downstream of the middle transect. The width of each transect was 1 m and the length varied based on the wetted width of the river. Therefore, a site surveyed represented three transects within a 20 meter longitudinal length of river. This provided an approximate 15% subsample of the area surveyed for each of the sites, regardless of the variable wetted width among the sites. Visual searches along each transect consisted of snorkel or dive techniques based on water depth and flow. Only the immediate surface of the river bottom was disturbed and surveyed for mussels. No excavation of material was conducted. All live mussels encountered along each transect were identified, measured, enumerated, and placed back in the river. Photo vouchers for each species were taken. The aggregation of the three transects represented the mussel fauna at a site and the data is reported as abundances. The mussel surveys were conducted by Lewis Environmental Consulting (Murray, Kentucky) with Chad Lewis as the principle investigator. No mussel surveys were conducted within the Nolin River or within the Green River downstream of the Nolin River, because river conditions were unsafe and excessively turbid due to water releases from the Nolin River dam.

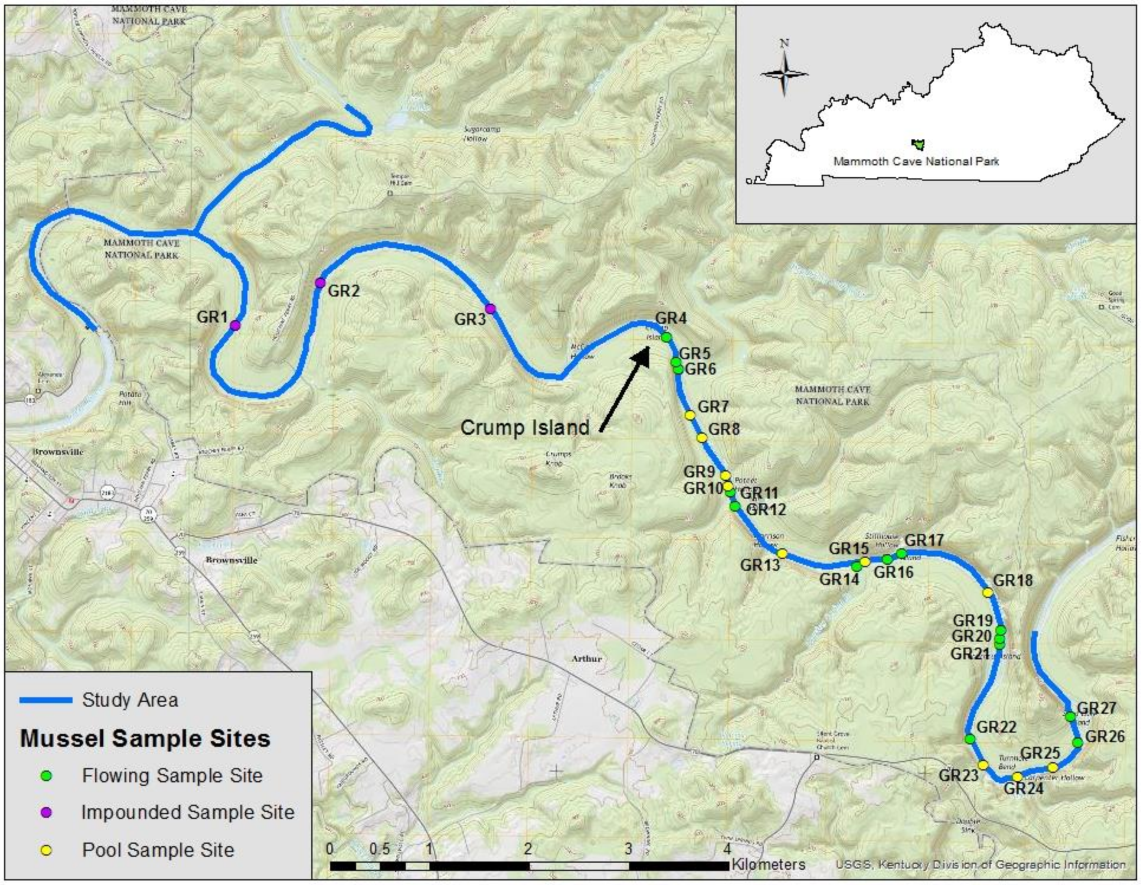

Figure 7. Mussel survey locations among habitat type.

Table 4. Mussel site location, habitat type, and date surveyed.

Stream	Site	Latitude	Longitude	Habitat type	Date surveyed
Green River	GR1	37.20694	-86.24488	Impounded	13-Oct-2017
Green River	GR2	37.21080	-86.23524	Impounded	13-Oct-2017
Green River	GR3	37.20854	-86.21601	Impounded	13-Oct-2017
Green River	GR4	37.20601	-86.19605	Flowing	13-Oct-2017
Green River	GR5	37.20381	-86.19495	Flowing	12-Oct-2017
Green River	GR6	37.20320	-86.19475	Flowing	12-Oct-2017
Green River	GR7	37.19897	-86.19329	Pool	12-Oct-2017
Green River	GR8	37.19693	-86.19205	Pool	12-Oct-2017
Green River	GR9	37.19352	-86.18933	Pool	12-Oct-2017
Green River	GR10	37.19263	-86.18899	Pool	11-Oct-2017
Green River	GR11	37.19207	-86.18877	Flowing	11-Oct-2017

Cont. Table 4. Mussel site location, habitat type, and date surveyed.

Green River	GR12	37.19077	-86.18820	Flowing	11-Oct-2017
Green River	GR13	37.18652	-86.18286	Pool	11-Oct-2017
Green River	GR14	37.18534	-86.17744	Flowing	10-Oct-2017
Green River	GR15	37.18586	-86.17348	Pool	10-Oct-2017
Green River	GR16	37.18600	-86.17096	Flowing	13-Oct-2017
Green River	GR17	37.18657	-86.16940	Flowing	11-Oct-2017
Green River	GR18	37.18310	-86.15956	Pool	10-Oct-2017
Green River	GR19	37.17962	-86.15809	Flowing	10-Oct-2017
Green River	GR20	37.17889	-86.15819	Flowing	9-Oct-2017
Green River	GR21	37.17841	-86.15825	Flowing	9-Oct-2017
Green River	GR22	37.16986	-86.16145	Flowing	9-Oct-2017
Green River	GR23	37.16743	-86.15997	Pool	10-Oct-2017
Green River	GR24	37.16641	-86.15614	Pool	13-Oct-2017
Green River	GR25	37.16726	-86.15213	Pool	10-Oct-2017
Green River	GR26	37.16958	-86.14930	Flowing	9-Oct-2017
Green River	GR27	37.17186	-86.15019	Flowing	11-Oct-2017

Fish

Five sites were selected to characterize the potential longitudinal differences in the fish communities (Table 5). Two sites were selected within the impounded section of the Green River, below Crump Island, and two sites within the free flowing section (formally transitional) of the Green River, above Crump Island (Figure 8). One site within the impounded section of the Nolin River was established. The sites were approximately 600 m in length and were considered typical locations that represented the broader reaches of river. Sampling techniques at each of the sites were standardized as much as possible based on the available, workable habitat. Overall, the goal was to capture the representative fish fauna at each site to establish baseline diversity and relative abundance data.

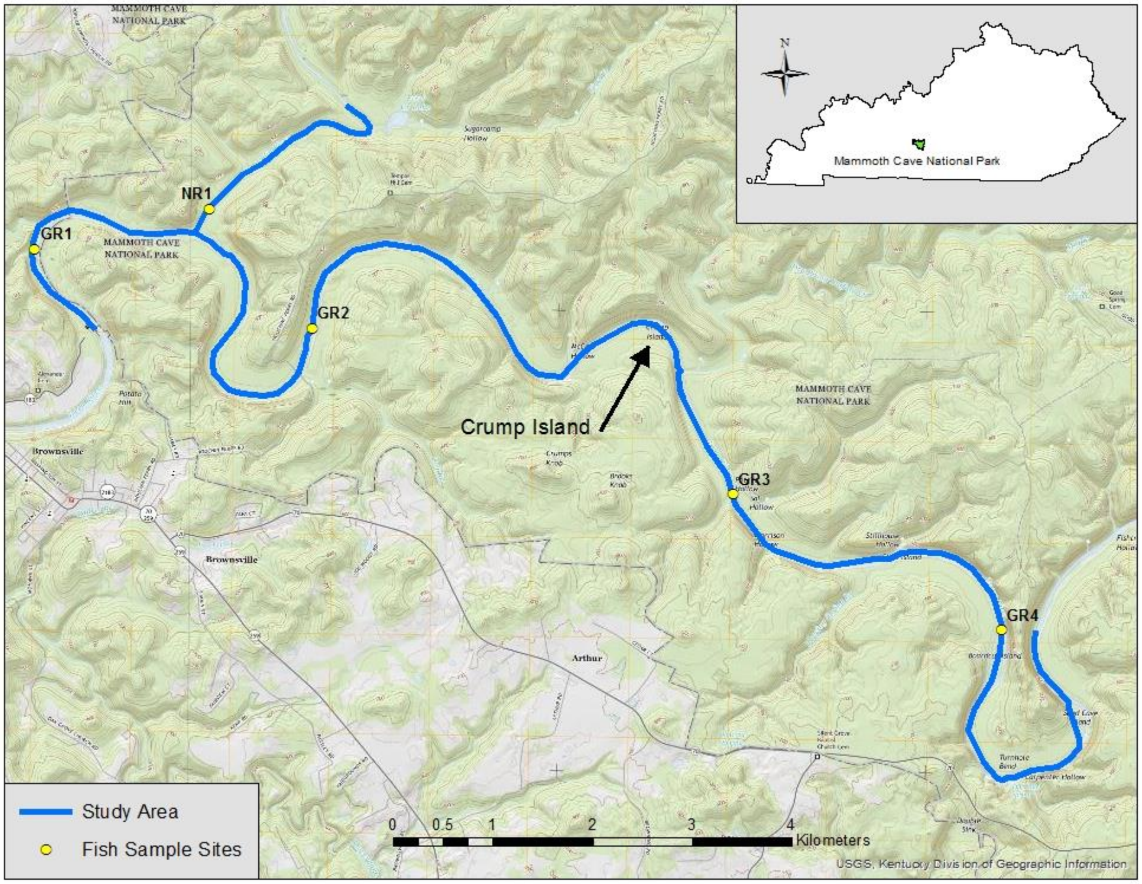

Figure 8. Fish sampling locations.

Boat electrofishing was conducted along each bank (downstream direction) for approximately 500 meters within the deeper areas of a site. The Nolin River site was much narrower than the four Green River sites and was shocked in a bank to bank zig-zag pattern for approximately 500 meters, instead of both banks being surveyed independently. At the two free flowing sites, riffle, run, and pool habitat sequences provided relatively shallow and workable areas, which were surveyed using a backpack electrofishing unit and a seine. Approximately 100-150 meters of the relatively shallow habitat was surveyed with these techniques. A Missouri trawl was used only at site GR2. Three hauls of the trawl were conducted to obtain the smaller fish within the benthic and pelagic zones of the deep mid channel area of the site. Technical issues prevented the use of the trawl within similar habitat at each of the sites. The fish community for each of the sites is the aggregation of the techniques and the data is reported as abundances.

Table 5. Fish site locations, sample date, and sample methods.

Stream	Site	Latitude	Longitude	Date	Methods
Green River	GR1	37.21370	-86.26759	22-Sept-17	Boat electrofish
Green River	GR2	37.20666	-86.23621	22-Sept-17	Boat electrofish and Missouri trawl
Green River	GR3	37.19182	-86.18853	24-Aug-17	Boat and backpack electrofish, and seine
Green River	GR4	37.17965	-86.15811	24-Aug-17	Boat and backpack electrofish, and seine
Nolin River	NR1	37.21739	-86.24785	22-Sept-17	Boat electrofish

In-stream habitat

A stratified random approach was used to determine site locations for in-stream habitat data. The study area was designated into impounded and free flowing sections of river based on the current hydrology. The general location of the hydrological change was near Crump Island on the Green River (Figure 9). Seven random sites were chosen from the impounded section (below Crump Island) within the Green (5 sites) and Nolin (2) rivers and eleven random sites were chosen within the free flowing section of the Green River (above Crump Island) (Table 6). The random geographical locations were generated from GIS. More sites were surveyed within the free flowing section, because of the greater habitat variability within that section of river. A site was an approximate 100 m reach of river. Approximately a 10% random subsample of the available habitat was surveyed within the free flowing section of river and approximately a 5% random subsample was conducted within the impounded section of river. Overall, the goal was to survey enough reaches within the study area to capture the habitat variation and to characterize the habitat within the impounded and free flowing sections of the study area.

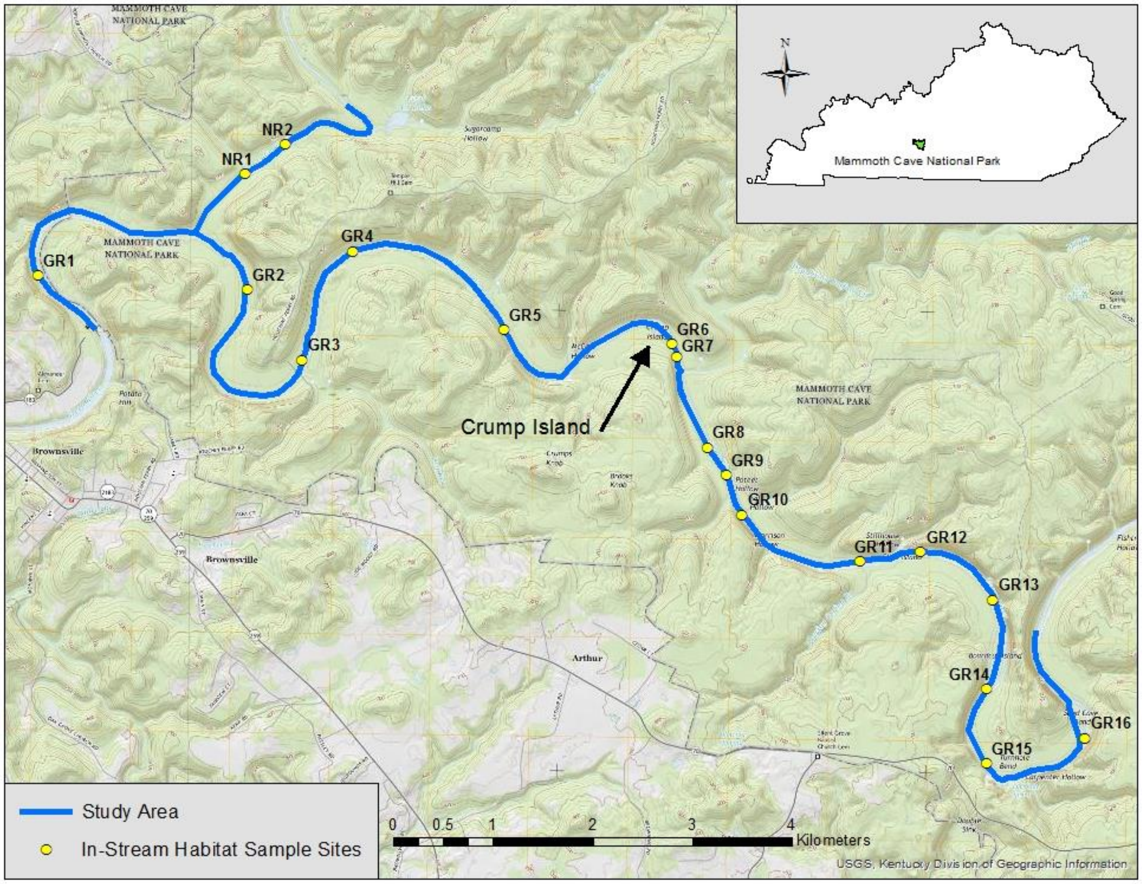

Figure 9. Site locations of in-stream habitat surveys.

For each site, data were collected along three bank to bank transects, which were located at the downstream boundary, the middle, and the upstream boundary of a site. Along each of the three transects, wetted width (m) was determined and at six evenly spaced points along each transect, water depth (m) and a substrate size category were determined. Data is reported as the mean wetted width, mean depth, and relative percentage of the substrate size categories from the respective sites of the two hydrological classifications. In addition, the middle transect was used to delineate between the downstream and upstream halves of a site. Within the downstream and upstream halves, the presence of large woody debris and snags (LWD, > 250 cm in diameter and > 2 m in length) were determined as present or absent (Figure 10A) and a percentage of bank failure was determined for the left and right descending banks (Figure 10B and C). Bank failure was defined as an obvious and a relatively recent bank collapse, which was perceived to be the result of quick and recent dewatering following the removal of L&D 6. Those data are reported as mean LWD relative frequency and mean percent bank failure for the two hydrological classifications.

A B C

Figure 10 (A-C). Presence of large woody debris and snags (A) and bank failure (B and C) within the study area.

Table 6. In-stream habitat survey locations and site hydrological classification.

Stream	Site	Latitude	Longitude	Hydrology
Green River	GR1	37.21128	-86.26720	Impounded
Green River	GR2	37.21010	-86.24390	Impounded
Green River	GR3	37.20375	-86.23730	Impounded
Green River	GR4	37.21361	-86.23170	Impounded
Green River	GR5	37.20657	-86.21450	Impounded
Green River	GR6	37.20540	-86.19550	Flowing
Green River	GR7	37.20424	-86.19500	Flowing
Green River	GR8	37.19605	-86.19150	Flowing
Green River	GR9	37.19352	-86.18930	Flowing
Green River	GR10	37.18994	-86.18750	Flowing
Green River	GR11	37.18577	-86.17420	Flowing
Green River	GR12	37.18668	-86.16730	Flowing
Green River	GR13	37.18236	-86.15910	Flowing
Green River	GR14	37.17429	-86.15980	Flowing
Green River	GR15	37.16757	-86.15980	Flowing
Green River	GR16	37.16988	-86.14867	Flowing
Nolin River	NR1	37.22061	-86.24389	Impounded
Nolin River	NR2	37.22328	-86.23930	Impounded

Results

Sediment, Bank Exposure, Slopes and Wetted Width of Stream

Twelve of 15 (80%) banks had exposed mud substrate, with GR9= mud + sand, GR11= sand, and GR12= cobble/boulder. The exposed bank measurement was greatest at plots along the downstream section (GR2 – GR5 averaged 4.4 m) as ponding when L&D 6 was functional would have been greatest along this section of the project and in general have a wider band of exposed bank than further upstream (this being less of the case in areas with steep cliffs or banks with less of a developed, wide floodplain). If you remove from the data GR10 due to a sand/mud bar-extension and GR11 due to a spot with irregular sediment buildup, then the stretch from GR6 through GR13 averaged just 3.1 meters. The steepest banks/slopes were scattered throughout the study area (GR2= 80% slope, GR6= 72% slope, GR8= 72% slope, GR12= 75% slope and GR13= 80% slope). Wetted stream width varied slightly across the study area with no distinctive narrowing from downstream to upstream, as might be evident over a longer span of stream corridor. Average wetted width distance on the Green River was 51.2 meters (13 plots), and 21.6 meters from the 2 plots on the Nolin River.

Vegetation

Summary tables (tables 7-10) have been created to show the common to frequently recorded species found across all plots. Table 6 represents the number of times a species was found dominant (dominant five) across all plots. Oriental lady's thumb or bunchy knotweed (*Persicaria longiseta*) was a dominant 11 of 15 times, and within seven of these plots the species percent cover was more than 10% of the plot. *Persicaria longiseta* is an invasive non-native plant originating from Asia and considered a "Significant Threat" by the Kentucky Invasive Plant Council (CISEH 2013). It is capable of recruitment and spread along disturbed soils that maintain moisture. Its dominant growth is expected to continue during this initial "post-dam" period of instability along the banks, e.g. remaining aggressive in areas of bank failure and areas of canopy loss /mature tree loss. Indian woodoats (*Chasmanthium latifolium*) was also a dominant 11 of 15 times, and within six of these plots the species % cover was more than 10% of the plot. *Chasmanthium latifolium* is a native grass, often found along stream corridors, like in the study area. As documented, it is capable of competing with aggressive species like *Persicaria longiseta.* Mild water-pepper *(Polygonum hydropiperoides)* was a dominant nine of 15 times and within nine of these plots (highest), the species percent cover was more than 10% of the plot.

Table 7. Species recorded as dominant across all plots.

Tree/Shrub/Herb	Species	# of times a dominant	# of times a dominant & having > 10% cover
herb	*Persicaria longiseta**	11	7
herb	*Chasmanthium latifolium*	11	6
herb	*Polygonum hydropiperoides*	9	8
herb	*Microstegium vimineum**	9	6
herb	*Leersia virginica*	5	2
herb	*Verbesina alternifolia*	5	2
herb	*Pilea pumila*	5	1
herb	*Amphicarpaea bracteate*	4	0
herb	*Ageratina altissima*	3	1
herb	*Polygonum punctatum*	3	1
herb	*Solidago rupestris***	2	1
shrub	*Lindera benzoin*	2	1
tree	*Platanus occidentalis*	1	1

All species names according to ITIS.; * Non-native invasive species.; **Species of conservation concern.

Polygonum hydropiperoides is another native species mostly restricted to wetland habitats (defined as a wetland obligate species throughout its range). As documented, it too is capable of competing with aggressive species like the associated *Persicaria longiseta.* Japanese stiltgrass (*Microstegium vimineum*) was a dominant nine of 15 times, and within six of these plots the species % cover was more than 10% of the plot. Considered a "Severe Threat" by the Kentucky Invasive Plant Council (CISEH 2013), this Asian intruder is one of the most abundant invasive plants throughout Mammoth Cave National Park (B. Yahn, field notes, 2012-2014, 2016). In conclusion, two of Kentucky's worst weeds are two of the most dominant species in the vegetation plots sampled; this expresses the degree of disturbance (soil erosion, bank failure, canopy loss, etc.) currently affecting the stream banks along the Green and Nolin Rivers.

Table 8 represents the number of times a tree species was recorded (woody stem counts) across all plots. Due to small plot size, few mature trees were captured along with low counts for saplings and small trees (for all plots). Although limited in stem counts and thus presence, the dominant trees seen along the corridor during transport to and from plots, were also evident in the data; common trees sampled were sycamore (*Platanus occidentalis*) and silver maple (*Acer saccharinum*).

Table 8. Trees recorded in plots (woody stem counts).

Tree/ Shrub/ Vine	Species	Mature tree(s) species found in 15 plots: count 1/plot, presence (absence)	Saplings & small tree(s) of each species found in 15 plots: count 1/plot, presence (absence)	% cover (shrub zone): presence (absence)
Tree	*Platanus occidentalis*	4	1	0
Tree	*Acer saccharinum*	3	0	1
Tree	*Ulmus rubra*	1	1	1
Tree	*Acer negundo*	1	1	0
Tree	*Diospyros virginiana*	0	1	1

All species names according to ITIS.

Table 9 represents the number of times a woody species was recorded in the shrub zone across all plots (taken from percent cover shrub data). Spicebush (*Lindera benzoin*) was by far the most common woody species in the shrub zone, recorded in 40% of all plots; this indicates that this native shrub is a common component in the streambank community but also has been known to increase after forest disturbances (B.Yahn, field notes, 2005-2017). Woolly dutchman's-pipe (*Aristolochia tomentosa*) was the second most common woody plant (a native woody vine) in the shrub zone, recorded in three plots, thus present 20% of the time. It is not known to be overly aggressive and thicket-forming but future monitoring should capture this species growth habits and response. Although giant cane (*Arundinaria gigantea*) was seen in healthy patches throughout the stream corridors, it was only recorded in the shrub zone of one plot. With *Arundinaria gigantea's* ability to colonize through spreading rhizomes, such a riparian species may be better equipped to increase/spread under current post-dam conditions (future monitoring should document such increases).

Table 9. Trees, shrubs, and woody vines recorded in the shrub zone of all plots (presence).

Tree/Shrub/Vine	Species	% cover (shrub zone): presence (absence)	% # present/ # plots *100
Shrub	*Lindera benzoin*	6	40
shrub/vine	*Aristolochia tomentosa*	3	20
Tree	*Acer saccharinum*	1	7
shrub/graminoid	*Arundinaria gigantea*	1	7
Tree	*Catalpa speciose*	1	7
Tree	*Celtis laevigata*	1	7
Tree	*Diospyros virginiana*	1	7
Shrub	*Hydrangea arborescens*	1	7
Shrub	*Hypericum prolificum*	1	7
Tree	*Ostrya virginiana*	1	7
Tree	*Ulmus rubra*	1	7
Tree	*Acer negundo*	0	0
Tree	*Platanus occidentalis*	0	0

All species names according to ITIS.

Table 10 represents the number of times a species was recorded in any subplot/quadrat. First, the four most dominant species (listed above) were also at or near the highest frequency encountered (*Microstegium vimineum, Persicaria longiseta*, *Chasmanthium latifolium, Polygonum hydropiperoides,* respectively*);* this was an expected result for the dominant species of the project. But further, other species might have been frequently encountered (times present) but not necessarily dominant. Those species not recorded as dominant in more than 60% of the plots, but still with a high subplot/quadrat frequency, include: Virginia cutgrass (*Leersia virginica)*, Canada clearweed (*Pilea pumila*), and American hog-peanut (*Amphicarpaea bracteata*). These are native species commonly found in Kentucky, especially in riparian or lowland mesic habitats, like the project setting (B.Yahn, field notes, 2005-2017). Their high frequency likely indicates that they are important plants making up the composition in the streambank community. In fact, population fluctuations or even loss of such species overtime might be an indicator of negative or unhealthy trends in long-term monitoring.

Table 10. # of Times a Species was Recorded in any Subplot/Quadrat

Tree/Shrub/Herb	Species	Subplots/ Quadrats
Herb	*Microstegium vimineum**	15
Herb	*Persicaria longiseta**	13
Herb	*Leersia virginica*	12
Herb	*Chasmanthium latifolium*	10
Herb	*Pilea pumila*	9
Herb	*Polygonum hydropiperoides*	8
Herb	*Amphicarpaea bracteata*	7
Herb	*Ageratina altissima*	4
Herb	*Boehmeria cylindrica*	4
Herb	*Symphyotrichum* sp.	4
Herb	*Polygonum punctatum*	3
Herb	*Verbesina alternifolia*	3
Herb	*Adiantum pedatum*	2
Bryophyte	*Conocephalum conicum*	2
Herb	*Glechoma hederacea**	2
Shrub	*Hydrangea arborescens*	2
Herb	*Polygonum hydropiperoides / P. punctatum*	2
Herb	*Symphyotrichum pilosum*	2

All species names according to ITIS.; * Non-native Invasive Species

These four summary tables provide an overall picture and general description of the vegetation strata that represents the project area along the Green and lower Nolin River. The canopy is dominated by sycamore (*Platanus occidentalis*) and silver maple (*Acer saccharinum*) with box elder (*Acer negundo*) and slippery elm (*Ulmus rubra*) also present. Understory trees are infrequent with the shrub zone also of low density but often with spicebush (*Lindera benzoin*) and sometimes woolly dutchman's-pipe (*Aristolochia tomentosa*). The herbaceous layer is dense beyond the exposed bank zone (noticeable "line from ponding"- the impact of old L&D 6), often with a mix of invasive exotics and wetland-riparian natives. Oriental lady's thumb or bunchy knotweed (*Persicaria longiseta*), Indian woodoats (*Chasmanthium latifolium*), mild water-pepper *(Polygonum hydropiperoides)* and Japanese stiltgrass (*Microstegium vimineum*) are the most frequently recorded dominants; with Virginia cutgrass (*Leersia virginica)*, Canada clearweed (*Pilea pumila*), and American hog-peanut (*Amphicarpaea bracteata*) important components of the herbaceous layer as well.

Macroinvertebrates

Approximately 7,500 macroinvertebrate specimens were collected from five quantitative, two semi-quantitative, and five qualitative samples from three impounded and two free flowing sites. The organisms represented 8 classes, 22 orders, 50 families, and 58 taxa (Appendix C). The most abundant and most diverse taxa group was the class Insecta, representing 8 orders and 38 families. Specifically, the families Chironomidae, Hydropsychidae, and Heptageniidae were the most abundant taxa from the Hester Dendy samples, comprising 88.2% – 97.3% of the assemblage across all sites (Appendix D). A few taxa were restricted to specific hydrological sections. Five taxa (Haliplidae, Psephenidae, Caenidae, Isonychiidae, and Taeniopterygidae) were only encountered at the two free flowing sites (GR3 and GR4) and weren't encountered at any of the impounded sites. In comparison, only one taxa, Pontoporeiidae, was encountered at each of the impounded sites, but absent from the free flowing sites. Overall, the assemblages among the sites were relatively similar, except for the Nolin River site (NR1)

The overall richness among the sites was greater at the free flowing sites (Table 11). The Nolin River was the least diverse and least abundant among all of the sites, regardless of sampling technique. Omitting the Nolin River site and only comparing the two impounded Green River sites (GR1 and GR2) to the two free flowing sites (GR3 and GR4), indicated that the overall richness was relatively the same (Table 12). Richness was slightly higher among the qualitative samples at the impounded sites, but slightly less diverse among the Hester Dendy samples. Richness and abundance from the kick net samples were greater at site GR3 than site GR4 (Appendix E).

Table 11. Diversity and abundance of macroinvertebrate samples.

	Qualitative			Quantitative	
Sites	Overall Richness	Qualitative richness	Wood richness	Hester Dendy richness (abundance)	Kick net richness (abundance)
GR1	32	29	19	14 (1103)	
GR2	37	31	19	15 (1766)	
GR3	42	24	14	24 (1786)	22 (570)
GR4	38	25	14	19 (1266)	17 (214)
NR1	20	16	12	11 (144)	

Table 12. Comparison of macroinvertebrate richness within two hydrological sections of the Green River.

Parameter	Hydrology	
	Impounded (2 sites)	Flowing (2)
Mean Richness:	34.5	40.0
Range:	32-37	38-42
Standard Deviation:	3.5	2.0

Freshwater Mussels

From 27 surveys, 482 live mussels representing 27 species were encountered (Appendix F.). Seventy-three percent of the individuals found were comprised of one of five species (Table 13). *Potamilus alatus*, *Quadrula quadrula*, *Cyclonaias pustulosa*, *Obliquaria reflexa*, and *Tritogonia verrucosa* were the five most common species (in order of abundance, respectively). Only two species (*Potamilus alatus* and *Megalonaias nervosa*) from four individuals were encountered within the three impounded sites surveyed. Flowing habitat had the greatest richness and abundance, as well as, the greatest mean richness per site and mean abundance per site. Seventeen species were encountered within the flowing habitat and were absent from all other types of habitat. Ten species were encountered within pool habitat, but three species (*Potamilus alatus*, *Obliquaria reflexa,* and *Quadrula quadrula*) comprised nearly 84% of the total abundance. The only federally endangered mussel species encountered during the surveys were one specimen each of *Cyprogenia stegaria* and *Plethobasus cyphyus*. However, the specimens of both imperiled species were estimated to be less than ten years old of age.

Table 13. Mussel diversity and abundance categorized by habitat type.

Family	Tribe	Species	Common Name	Flowing (n=14)	Pool (n=10)	Impounded (n=3)
Unionidae						
	Anodontini					
		Lasmigona complanata	White Heelsplitter	2	1	
		Lasmigona costata	Flutedshell	1		
		Strophitus undulatus	Creeper	2		
	Amblemini					
		Amblema plicata	Threeridge	2		
	Lampsilini					
		Actinonaias ligamentina	Mucket	16		
		Cyprogenia stegaria	Fanshell	1		

Cont. Table 13. Mussel diversity and abundance categorized by habitat type.

Lampsilini					
	Ellipsaria lineolata	Butterfly	7		
	Lampsilis cardium	Plain Pocketbook	12		
	Lampsilis ovata	Pocketbook	18	1	
	Lampsilis siliquoidea	Fatmucket	1		
	Leptodea fragilis	Fragile Papershell	7	1	
	Ligumia recta	Black Sandshell	3	1	
	Obliquaria reflexa	Threehorn Wartyback	45	13	
	Potamilus alatus	Pink Heelsplitter	78	23	1
	Ptychobranchus fasciolaris	Kidneyshell	3		
	Truncilla truncata	Deertoe	4		
Pleurobemini					
	Elliptio crassidens	Elephantear	1		
	Eurynia dilatata	Spike	5		
	Fusconaia subrotunda	Longsolid	1		
	Plethobasus cyphyus	Sheepnose	1		
	Pleurobema sintoxia	Round Pigtoe	2		
Quadrulini					
	Cyclonaias pustulosa	Pimpleback	61	1	
	Cyclonaias tuberculata	Purple Wartyback	1		
	Megalonaias nervosa	Washboard	28	3	3
	Quadrula quadrula	Mapleleaf	76	11	
	Theliderma metanevra	Monkeyface	2		
	Tritogonia verrucosa	Pistolgrip	42	1	
		Total richness:	27	10	2
		Mean richness/site:	9.29	2.70	0.67
		Total abundance:	422	56	4
		Mean abundance/site:	30.14	5.60	1.33

Fish

Over 1,500 individuals representing 58 native species of fish were collected from five sites (Appendix G). *Notropis micropteryx*, *N. volucellus*, *Moxostoma erythrurum*, *Percina evides*, and *Lepomis megalotis* were the five most abundant species, in respective order. *Dorosoma cepedianum*, *Cyprinella spiloptera*, *N. atherinoides*, *M. erythrurum*, and *L. macrochirus* were common and encountered at each site. Ten species were only encountered at sites within the free flowing section of the river, such as *Erimystax dissimilis*, *Hybopsis amblops*, *N. ariommus*, *Phenacobius uranops*, and *Hypentelium nigricans*. No species were encountered strictly at sites located within the impounded section of the study area. Richness at free flowing sites was over twice as great as the impounded sites (Table 14). Mean abundance was approximately four times greater at flowing sites than impounded sites. However, this is most likely a combination of better habitat and the capability to use of a seine and backpack electrofishing unit during the collection of fishes at the flowing sites. *Notropis micropteryx* and *N. volucellus* were two species that were common and easily captured with a seine, together those species comprised approximately 47% and 42% of the collection at sites GR3 and GR4, respectively.

Table 14. Comparison of fish richness and abundance within two hydrological sections of the Green and Nolin rivers.

	Hydrology	
Parameter	Impounded (3 sites)	Flowing (2)
Mean richness:	20.0	44.0
Range:	14-24	39-49
Standard Deviation:	5.3	7.1
Mean abundance:	135.3	559.5
Range:	47-252	513-606
Standard Deviation:	105.4	65.7

In-stream habitat

Physical habitat measurements were taken from seven impounded sites and eleven free flowing sites, which was an approximate 5% and 11% random subsample of the available habitat, respectively. The mean wetted width was greater at the free flowing sites than at the impounded sites. This is mostly an artifact that the Nolin River site, which is smaller than the Green River, was included among the impounded sites (Table 15). However, the mean depth was greater at the impounded site than at the free flowing sites.

The composition of the in-stream substrates differed drastically because of the large relative abundance of mud substrate within the impounded section of the river. The relative abundance of mud at the impounded sites was 67% and the aggregation of mud, sand and gravel comprised 94% of the available substrate within the impounded section of the river. Only 71% of the free flowing sites was comprised of mud, sand and gravel. Pebble, cobble, and boulder comprised a substantial amount of the available habitat, with nearly 30% composition. Overall, the substrates in the free flowing section were more evenly distributed and larger in size than at sites within the impounded section of the river.

Table 15. Physical habitat measurements.

Parameter	Flowing (11)	Pool (7)
Mean wetted width (m)	50.2	45.2
Mean depth (m)	1.8	2.7
Mud (%)	0.25	0.67
Sand (%)	0.22	0.17
Gravel (%)	0.24	0.10
Pebble (%)	0.15	0.02
Cobble (%)	0.09	0.01
Boulder (%)	0.05	0.02
Bedrock (%)	0.01	0.01
Mean bank failure (%)	14.5	55.7
Mean LWD Relative frequency	0.80	0.82

The banks along the study area exhibited frequent areas of excessive erosion and collapse. Measurements of the recently exposed banks indicated that over 50% of the banks within the impounded section of the river have experienced substantial and recent bank failure. Sites within the free flowing section have experienced bank failure, but only an approximate 15% bank failure was estimated.

Large woody debris (LWD) and snags are a common habitat feature within the river. Measurements of the relative frequency of LWD and snags were made to estimate the prevalence of the habitat. Both the impounded and the free flowing sections of river exhibited a large presence of LWD. Both sections of river had a relative frequency of LWD over 80%.

Discussion

For a thorough assessment of the environmental changes associated with a dam removal, it is recommended pre- and post- monitoring of the ecosystem be conducted for five to ten years (Kondolf 1995). Unfortunately, data prior to the removal of L&D 6 are sparse and no prior monitoring directly associated with the recent dam removal was made. Macroinvertebrate studies by Pond (1996) and Grubbs and Taylor (2004) are the only studies available that looked at the conditions of the Green River in anticipation of the removal of L&D 6. The compilation of physical and biological data obtained during summer 2017 established baseline data for monitoring and assessing the environmental conditions of the Green and Nolin rivers following the removal of L&D 6.

Vegetation

There was no apparent trend or longitudinal shift in the vegetation along the Green River. However, the most conservative species recorded in the study, rock goldenrod (*Solidago rupestris*), was only found upstream of Crump Island (GR8 and GR12; possibly at NR2 as well). Rock goldenrod is considered "secure" = S4 in Kentucky, but "critically imperiled" = S1 in Virginia and Tennessee, and "possibly extirpated" = SH in Pennsylvania and Maryland (NatureServe 2017). Although conjecture, this finding may presume that a less impacted and less flooded condition is more suitable to species that are unable to colonize and/or compete in a short period of time after disturbance (i.e., those more conservative species that tend to decline under anthropogenic disturbance, like dam removal), would benefit more favorably in such a condition. Thus, overall conditions of little soil disturbance and greater stability, with minimal bank failure and low tree mortality will support more conservative plant species creating a higher quality stream-side forest. The sites above Crump Island (GR8 – G13) may prove more stable and more distinguishable from the downstream sites as more time passes.

Although only two sites were surveyed along the Nolin River, the overall appearance of the riparian zone was noticeably different than the appearance of the Green River. Tree mortality was much higher in the lower section of Nolin River, creating an environment where more light was available to lower strata, which caused an increase in herbaceous vegetation growth. Much of this growth was invasive species, such as *Persicaria longiseta* and *Microstegium vimineum*, with *Microstegium vimineum* being the most dominant species recorded at both Nolin River sites. The Nolin River was not only influenced by L&D 5 and L&D 6, but also (still) influenced by repeated cold-flooding and scouring events when water is released upstream from Nolin River Dam.

This monitoring project is at the initial stage with this first season completed, as it is important to discuss the vegetation sampling schedule for any multi-season study. It is recommended that continued monitoring occur within the immediate growing season or at least as soon as the 2nd growing season after the 2017 sampling. One reason for this is to capture any changes in community strata as it happens. It is critical to sample within a close time frame because elements that show the response and function of the community (e.g. woody stem counts) may not be captured if intervals between monitoring events are too long. Resampling of the 2017 sites with the potential to add a few other sites to the schedule are decisions that also need to be made before the sampling occurs.

Macroinvertebrates

The studies by Pond (1996) and Grubbs and Taylor (2004) indicated that the macroinvertebrate fauna within the free flowing section was distinct from the transitional and impounded sections of the river. After the removal of the dam the transitional section shifted to a free flowing section within the Green River. The overall richness between the contemporary free flowing and the impounded section of the Green River were relatively similar and the fauna was comprised mostly of the same three to five taxa among all of the Green River sites. This suggests that the macroinvertebrate fauna was largely an artifact of the prior conditions and the fauna has not shifted to indicate new free flowing hydrological conditions. Within these particular sections of river, Grubbs and Taylor (2004) found the historical transitional and impounded sections were ecological similar. Indicating that even though hydrological conditions may reveal run and riffle habitat seasonal, the seasonal impoundment of those habitats had a greater influence on the fauna. Recovery of the fauna within these sections of river may take a few years so that scouring of habitat and the redistribution of substrates can occur and stabilize.

The most distinct site was within the Nolin River. The fauna had the least diversity and abundance among all of the sites. The lower reach of the Nolin River experiences extreme hydrological conditions, frequently, and often within short periods of time. The lower reach is still impounded from L&D 5 and it periodically receives large amounts of hypolimnetic water from the Nolin River dam. This creates an environment where the stagnant water is periodically flushed at high velocities with cold water, which scours the channel. The macroinvertebrate fauna, especially from the Hester Dendy samples was indicative of the scouring. A few plates of the HD units were relatively free of colonization. It is not anticipated that the fauna will recover or change until the influences from L&D 5 and Nolin River dam are addressed.

Freshwater mussels

Prior mussel studies (Cicerello and Hannan 1990; Layzer 2002) within the Green River at MCNP indicated that the fauna was diverse and impacted from the presence of L&D 6. Our results indicated the diversity and abundance of mussels were highly associated with the hydrological conditions. The mussel fauna within the section of river that is still impounded from L&D 5 (below Crump Island) was depauperate, while the free flowing section was more abundant and diverse, with the flowing habitat being more diverse and abundant than the pool habitat. However, the fauna within the contemporary free flowing section was indicative of impoundment, at least seasonally. The majority of individuals encountered were comprised of pool tolerant species (i.e., *Potamilus alatus* and *Quadrula quadrula*) and only a few individuals from species that have a strong association with lotic habitats (i.e., *Amblema plicata*, *Actinonaias ligamentina*, and *Ptychobranchus fasciolaris*) were present. The reaches of river furthest from the footprint of L&D 6 most likely will recover the quickest and represent a fauna more indicative of lotic habitat (Vaughn and Taylor 1999; Tiemann et al. 2016). Mussel are relatively longer lived and have a longer life history per individual compared to other aquatic invertebrates so the shift from a lentic dominant fauna to a lotic dominant fauna most likely will take a couple decades.

Fish

The overall fish fauna indicated that a diverse assemblage occurs within the Green River. The Nolin River site was the least diverse and least abundant site. The presence of the Nolin River dam and the influence from L&D 5 limits the fauna substantially. The free flowing sites on the Green River were greater in diversity and abundance than the impounded sites. Also, several species occurred within the free flowing section that were not encountered at the impounded sites. The greater diversity and abundance were a result of a more complex flow regime and habitat diversity found at the free flowing sites. It is unclear if the fish used these habitats previously when the historical transitional section experienced low water levels or if the fish have colonized these habitats immediately following dam removal. The lows numbers of benthic species suggest that the fish might be transient individuals. However, the abundance of pelagic minnow species that often associate with swift, rocky habitat suggest that their presence might have persisted within the former transitional section, even during higher water levels. Over time benthic species and abundance should increase within both sections of the river, but primarily within the free flowing section.

In-stream habitat

No strong patterns were observed with the data except that substrates and bank failure were different among the impounded and free flowing sections of the river. The data also indicated that the Nolin River is heavily impacted from the Nolin River dam and L&D 5. The impounded section of the Green and Nolin rivers exhibited tremendous amount of bank failure. This is most likely because those sections were more greatly impacted from the inundation of pool 6 and when the dam was removed the soils that were once saturated dried and no longer supported the weight of vegetation, rock, and other material.

The free flowing section experienced bank failure too, but not to the extent encountered within the impounded section. It is unclear if the large volume of soil that fell into the impounded section contributed substantially to the large amount of mud substrate within the impounded section, or if the smaller substrate was the result of the dam minimizing the flow which caused suspended particles to settle, or both.

Management implications

The removal of L&D 6 is perceived to have ecological benefits to the ecosystem. Without any prior dam removal data, it is not possible to compare before and after dam removal changes, but with continued monitoring it will be possible to draw inference on the changes that will occur over time and determine any trends that may occur. The rate of recovery will vary with each faunal group and could vary among sites and hydrological regime (Pollard and Reed 2004), but substantial changes could occur within as little as a few years. Burroughs et al. (2010) documented the recolonization of fishes following a dam removal within four years and Kanehl et al. (1997) documented improvements to select fishes within five years of dam removal. It is recommended that monitoring of the biological and physical habitat continue within the Green and Nolin rivers. Specifically, monitoring of vegetation (riparian zone), macroinvertebrate, fish, and in-stream habitat should be conducted on an annual basis for the next five years. In conjunction, monitoring of freshwater mussels should continue too, but at an interval of every five years for the next twenty years. Currently, no physical enhancements to habitats or augmentation of fish or mussel populations is recommended. It recommended that the macroinvertebrate collections from 2017 and future collections be identified to the genus taxonomic level, or further, to provide the necessary resolution for function feeding guild analysis. Lastly, it is recommended that with further monitoring efforts and the accumulation of data a statistical analysis of the data be conducted to fully understand the recovery of the river and its biological and physical features.

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References

Bellmore, J.R., J.J. Duda, L.S. Craig, S.L. Green, C.E. Torgersen, M.J. Collins, and K. Vittum. 2017. Status and trends of dam removal in the United States. Wiley Interdisciplinary Reviews: Water 4:e1164. Doi: 10.1002/wat2.1164.

Burroughs, B.A., D.B. Hayes, K.D. Klomp, J.F. Hansen, and J. Mistak. 2010. The effects of the Stronach Dam removal on fish in the Pine River, Manistee County, Michigan. Transactions of the American Fisheries Society 139(5): 1595-1613.

Cicerello, R.R. and R.R. Hannan. 1990. Survey of the freshwater unionids (mussels) (Bivalvia: Margaritiferidae and Unionidae) in the Green River in Mammoth Cave National Park, Kentucky. Frankfort: Kentucky State Nature Preserves Commission.

Cicerello, R.R. and R.R. Hannan. 1991. Survey and review of the fishes of Mammoth Cave National Park, Kentucky. Frankfort: Kentucky State Nature Preserves Commission.

[CISEH] Center for Invasive Species and Ecosystem Health. Kentucky Invasive Plant Council: Exotic Invasive Plants of Kentucky (2013). Retrieved November, 2017, from https://www.se-eppc.org/ky/KYEPPC_2013list.pdf

Foley, M.M. and ten coauthors. 2017. Landscape context and the biophysical response of rivers to dam removal in the United States. PLOS One https://doi.org/10.1371/journal.pone.0180107.

Guenther, C.B. and A. Spacie. 2006. Changes in fish assemblages structure upstream of impoundments within the upper Wabash River basin, Indiana. Transactions of the American Fisheries Society 135(3): 570-583.

Grubbs, S.A. and J.M. Taylor. 2004. The influence of flow impoundment and river regulation on the distribution of riverine macroinvertebrates at Mammoth Cave National Park, Kentucky, U.S.A. Hydrobologia 520: 18-28.

Haag, W.R. 2012. North American Freshwater Mussels: Natural History, Ecology, and Conservation. Cambridge University Press, New York. 505 pp.

Hayes, D.B., H. Dodd, and J. Lessard. 2006. Effects of small dams on cold water stream fish communities. American Fisheries Society Symposium: 587-602.

[ITIS] Integrated Taxonomic Information System on-line database. Retrieved November, 2017, from http://www.itis.gov.

Layzer, J.B. 2002. Status of the freshwater mussel fauna in the Green River within Mammoth Cave National Park – a preliminary assessment. In proceedings of Mammoth Cave National Park's ninth science conference: 51-53.

Kanehl, P.D., J. Lyons, and J.E. Nelson. 1997. Changes in habitat and fish community of the Milwaukee River, Wisconsin, following removal of the Woolen Mills Dam. North American Journal of Fisheries Management 17(2): 387-400.

Kondolf, G.M. 1995. Managing bedload sediments in regulated rivers: Examples from California, USA. Geophysical Monograph 89:165–176.

Oliver, M. and G. Grant. 2017. Liberated rivers: lessons from 40 years of dam removal. Science Findings 193. Portland, Oregon: United States Department of Agriculture, Forest Science, Pacific Northwest Research station. 5 pp.

Pollard, A.I. and T. Reed. 2004. Benthic invertebrate assemblage change following dam removal in a Wisconsin stream. Hydrobiologia 513: 51-58.

Pond, G.J. 1996. Upstream effects of a dam on the longitudinal and seasonal distribution of macroinvertebrate taxonomic and functional feeding guilds in the Green River within Mammoth Cave National Park, Kentucky. Masters Thesis, Eastern Kentucky University, Richmond, Kentucky. 125pp.

Winston, M.R., C.M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society 120(1): 98-105.

National Park Service. 1983. Mammoth Cave National Park general management plan. National Park Service, Denver, Colorado, U.S.A.

NatureServe. 2017. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. Arlington,VA. http://www.natureserve.org/explorer/. Accessed January 2017.

Tiemann J.S., S.A. Douglas, A.P. Stodola, and K.S. Cummings. 2016. Effects of lowhead dams of freshwater mussels in the Vermillion River basin, Illinois, with comments on a natural dam removal. Transactions of the Illinois State Academy of Science 109: 1-7.

[USACOE] United States Army Corps of Engineers. 1981. Water resources development in Kentucky, 1981. United States Army Corps of Engineers, Louisville District, Louisville, Kentucky, U.S.A.

Vaughn, C.C. and C.M. Taylor. 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. Conservation Biology 13(4): 912-920.

Appendix A. Riparian vegetation field data sheet.

Photo and Plot Sampling: Green River Dam Removal (within Mammoth Cave NP)

Date: 9/19/17

Surveyor(s): B. Yahn, K. McDonald

Plot/Photopoint Station #: GR12

Distance from Dam removal (every 1 mi): 11.5 mi

Middle of Stream

ACCURACY 18FEET

Lat (DD): 37.16720833

Long (DD): -86.15212167

Photopoint#

North or East PP: 104

South or West PP: 103

2.9 6.2 Wetted Width of Stream (m) 39.1 CENTER OF STREAM

Bank-facing direction (w robel pole)	photo #/name(s): 105, 106	ACCURACY: 18FEET
Azimuth 166	Lat (DD): 37.16313083	
GR12_P	Long (DD): -86.15208750	
Downstream-facing direction	photo #/name(s): 108	Azimuth 248
Upstream-facing direction	photo #/name(s): 107	Azimuth 93
exposed bank substrate (circle one)	sand, mud, gravel, cobble, boulder, loam soil, litter, moss, other (?)	
exposed bank to veg "line": distance (m)	3.3	
distance to top of bank (m)	15+	
% slope (water line to top of bank)	75%, 34°	

Plot #

Dominant 5 species (2 m x 12 m)	% cover	
HYDARB	5-10	
LINBEN	1-5	
SOLGRA? (COLLECTED)	20-30	
ASTER SPA (COLLECTED)	5-10	
OSTVIR	1-5	
CHALAT	1-5	

Trees and Shrubs

Canopy -subcanopy (>5 m) (circle one): >75% closed, 50-75% closed, 50-75% open, >75% open

Short and Tall Shrub Strata (0.5 - 5 m) (circle one): 0%, 0-25%, 25-50%, 50-75%, >75%

Stem Counts

Woody spp. in plot (Seedlings (NA))	Sapling 1: <2 cm dbh	Sapling 2: (>2 cm <5 cm	Small Tree (>5 cm <15 cm dbh)
All shrubs and trees			
Individual mature trees	Medium Tree Count (>15 cm < 35 cm dbh)	Large Tree Count (>35 cm < 75 cm dbh)	X-Large Tree Cnt (>75 cm+ dbh)
PLAOCC,	DEAD SNAG		

shrub spp.: % cover (circle one)	short and tall shrub strata (0.5 - 7 m)			
HYDRANG 5-10%	1-25%	25-50%	50-75%	>75%
LINBEN 1-5%	1-25%	25-50%	50-75%	>75%
OSTVIR 1-5%	1-25%	25-50%	50-75%	>75%
HYPERICUM SPA (COLLECTED) minute	1-25%	25-50%	50-75%	>75%

Quarter meter square: plot a L11

Species	% cover
TOXRAD	0-5
MAIDEN HAIR FERN	5-10
ASTER SPA (COLLECTED)	0-5
SOLFLE/SPH? (COLLECTED)	10-15
AMPBRA	0-5
LIZARD SKIN (ID KENDALL)	20-30
LEEVIR	0-5
HYDARB	5-10

Notes:

Quarter meter square: plot b R10

Species	% cover
MAIDENHAIR FERN	5-10
BOECYL?	~~[illegible]~~ 0-5
ASTER SPA	0-5
LIZARD SKIN (ID KENDALL)	0-5
OTHER MOSSES	0-5
HYDRANGEA ARBORESCENS	MINUTE
DRYMAR? OR ATHFEL	0-5

Notes:

Appendix B. Riparian vegetation species presence by site.

Family	Species	Common Name	**GR1**	**GR2**	**GR3**	**GR4**	**GR5**	**GR6**	**GR7**	**GR8**	**GR9**	**GR10**	**GR11**	**GR12**	**GR13**	**NR1**	**NR2**
Anacardiaceae																	
	Toxicodendron radicans	Poison Ivy												X			
Apiaceae																	
	Cryptotaenia canadensis	Canada Honewort	X														
Aristolochiaceae																	
	Aristolochia tomentosa	Woolly Dutchman's-Pipe	X				X	X							X		
Asteraceae																	
	Verbesina alternifolia	Wingstem		X					X		X		X		X	X	X
	Solidago rupestris	Rock Goldenrod								X				X			
	Symphyotrichum dumosum	Rice Button Aster						X									
	Symphyotrichum ontarionis	Bottomland Aster						X									
	Symphyotrichum pilosum	Hairy White Oldfield Aster												X			
	Symphyotrichum sp.	An Aster				X							X		X		
	Ageratina altissima	White Snakeroot		X												X	X
	Bidens comosa	Three-Lobe Beggartick						X									
	Bidens sp.	A Beggartick								X							
Betulaceae																	
	Ostrya virginiana	Eastern Hop-Hornbeam												X			
Bignoniaceae																	
	Campsis radicans	Trumpet-Creeper				X											
	Catalpa speciosa	Northern Catalpa					X										
Brassicaceae																	
	Unknown Bassicaceae	A Mustard					X										
Cannabaceae																	
	Celtis laevigata	Sugarberry							X								

Cont. Appendix B. Riparian vegetation species presence by site.

Family	Species	Common Name	**GR1**	**GR2**	**GR3**	**GR4**	**GR5**	**GR6**	**GR7**	**GR8**	**GR9**	**GR10**	**GR11**	**GR12**	**GR13**	**NR1**	**NR2**
Caprifoliaceae																	
	Triosteum aurantiacum	Coffer Tinker's-Weed													X		
Conocephalaceae																	
	Conocephalum conicum	Conocephalum												X			
Cyperaceae																	
	Carex sp.	A Sedge	X														
Dryopteridaceae																	
	Dryopteris marginalis	Marginal Wood-Fern												X			
Ebenaceae																	
	Diospyros virginiana	Persimmon	X														
Fabaceae																	
	Amphicarpaea bracteata	American Hog-Peanut		X						X			X	X		X	X
Hydrangeaceae																	
	Hydrangea arborescens	Wild Hydrangea												X			
Hypericaceae																	
	Hypericum mutilum	Slender St. John's-Wort	X														
	Hypericum prolificum	Shrubby St. John's-Wort												X			
	Hypericum sp.	A St. John's-Wort						X									
Lamiaceae																	
	Glechoma hederacea	Ground Ivy		X	X												
	Lamium purpureum	Purple Deadnettle						X			X						
	Stachys sp.	A Hedge Nettle										X					
Lauraceae																	
	Lindera benzoin	Spicebush	X					X						X	X	X	X

Cont. Appendix B. Riparian vegetation species presence by site.

Family	Species	Common Name	**GR1**	**GR2**	**GR3**	**GR4**	**GR5**	**GR6**	**GR7**	**GR8**	**GR9**	**GR10**	**GR11**	**GR12**	**GR13**	**NR1**	**NR2**
Oxalidaceae																	
	Oxalis stricta	Upright Yellow Wood-Sorrel													X		
Platanaceae																	
	Platanus occidentalis	Sycamore					X		X		X			X		X	
Poaceae																	
	Leersia virginica	Virginia Cutgrass	X	X	X	X	X				X	X	X	X	X		
Poaceae																	
	Microstegium vimineum	Japanese Stiltgrass	X		X		X	X	X	X	X	X	X			X	X
	Arundinaria gigantean	Giant Cane					X										
	Chasmanthium latifolium	Indian Woodoats	X	X	X		X	X	X	X	X		X	X	X	X	
	Cinna arundinacea	Sweet Woodreed															X
	unknown Poaceae	A Grass															X
Polygonaceae																	
	**Persicaria longiseta*	Oriental Lady's Thumb	X		X	X		X	X	X	X	X	X		X	X	X
	Polygonum hydropiperoides	Mild Water Pepper		X			X	X	X	X	X	X					
Polygonaceae																	
	Polygonum hydropiperoides + *P. punctatum*	n/a			X	X											
	Polygonum punctatum	Dotted Smartweed	X				X						X				
	Polygonum virginianum	Jumpseed				X											
Pteridaceae																	
	Adiantum pedatum	Northern Maidenhair-Fern												X			
Ranunculaceae																	
	Clematis sp.	A Clematis														X	

Cont. Appendix B. Riparian vegetation species presence by site.

Family	Species	Common Name	**GR1**	**GR2**	**GR3**	**GR4**	**GR5**	**GR6**	**GR7**	**GR8**	**GR9**	**GR10**	**GR11**	**GR12**	**GR13**	**NR1**	**NR2**
Sapindaceae																	
	Acer negundo	Box Elder				X									X		
	Acer saccharinum	Silver Maple		X	X								X				X
Smilacaceae																	
	Smilax tamnoides	Bristly Greenbrier													X		
Solanaceae																	
	Physalis virginiana	Virginia Ground-Cherry								X							
Ulmaceae																	
	Ulmus rubra	Slippery Elm			X		X										
Urticaceae																	
	Pilea pumila	Canada Clearweed	X	X	X	X	X	X				X	X			X	X
	Boehmeria cylindrica	Smallspike False Nettle			X					X		X		X			
Verbenaceae																	
	Verbena urticifolia	White Vervain						X									
Violaceae																	
	Viola sororia	Woolly Blue Biolet				X											
Vitaceae																	
	Parthenocissus quinquefolia	Virginia Creeper					X										
Other																	
	Unknown Snag/Recently Dead	n/a													X		
	Unknown Mosses	n/a												X			
	Unknown Spp.	n/a			X												X
	Unknown Forb	n/a													X		

**Persicaria longiseta synonym* = *Polygonum cespitosum* var. *longisetum* according to ITIS.

Appendix C. Macroinvertebrate taxa presence by site.

Class	Order	Family	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**
Turbellaria							
		Unknown Turbellarian		X	X	X	X
(Phylum) Nematoda							
		Unknown Nematode			X		
Clitellata							
	Haplotaxida						
		Tubificidae	X	X		X	X
	Lumbriculida						
		Lumbriculidae	X		X	X	X
Bivalvia							
		Unknown Bivalve		X			
	Veneroidea						
		Corbiculidae	X		X	X	
		Sphaeriidae	X		X		
Gastropoda							
	Basommatomorpha						
		Ancylidae (Planorbidae)	X	X	X	X	X
		Physidae		X	X		
		Planorbidae	X	X			
	Neotaenioglossa						
		Hydrobiidae	X				
		Pleuroceridae	X	X	X	X	X
Arachnida							
	Trombidiformes						
		Hydracarina	X	X	X	X	
Insecta							
	Coleoptera						
		Dryopidae		X	X	X	
		Elmidae	X	X	X	X	X

Cont. Appendix C. Macroinvertebrate taxa presence by site.

Class	Order	Family	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**
Insecta							
	Coleoptera						
		Gyrinidae			X		
		Haliplidae			X	X	
		Hydrophilidae	X	X	X	X	
		Psephenidae			X	X	
		Scirtidae	X				
	Diptera						
		Ceratopogonidae	X	X	X	X	
		Chironomidae	X	X	X	X	X
		Empididae	X	X	X	X	
		Simuliidae			X		X
		Tipulidae	X				
	Ephemeroptera						
		Baetidae	X	X	X	X	X
		Caenidae			X	X	
		Ephemerellidae			X		
		Ephemeridae	X	X	X		
		Heptageniidae	X	X	X	X	X
		Isonychiidae			X	X	
		Leptohyphidae	X	X	X	X	X
	Hemiptera						
		Corixidae		X			
		Gerridae			X	X	X
	Megaloptera						
		Corydalidae	X		X	X	
	Odonata						
		Aeshnidae		X	X		
		Coenagrionidae	X	X	X	X	X

Cont. Appendix C. Macroinvertebrate taxa presence by site.

Class	Order	Family	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**
		Corduliidae	X	X	X	X	X
		Gomphidae	X	X	X	X	
		Macromiidae			X	X	X
	Plecoptera						
		Perlidae	X	X	X	X	
		Pteronarcyidae	X	X	X	X	
Insecta							
	Plectoptera						
		Taeniopterygidae			X	X	
		Unknown Plecopteran A (Pteronarcyidae?)		X			
		Unknown Plecopteran B (Taeniopterygidae?)		X			
		Unknown Plecopteran C (Capniidae or Taeniopterygidae?)			X		
		Unknown Plecopteran D (Perlidae or Perlodidae?)				X	
	Trichoptera						
		Brachycentridae		X		X	
		Hydropsychidae	X	X	X	X	X
		Hydroptilidae	X	X	X	X	
		Leptoceridae	X	X	X	X	
		Polycentropodidae	X	X	X	X	X
		Unknown Trichopotera A (Lepidostomatidae?)				X	
		Unknown Trichopteran B (Hydropsychidae?)		X			
Malacostraca							
	Amphipoda						
		Gammaridae		X			
		Pontoporeiidae	X	X			X
	Decapoda						
		Cambaridae			X	X	X
		Palaemonidae - *Palaemonetes kadiakensis*		X			
	Isopoda						
		Asellidae	X	X		X	X

Appendix D. Macroinvertebrate taxa Hester-Dendy abundance by site.

Class	Order	Family	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**
Turbellaria							
		Unknown Turbellarian					2
(Phylum) Nematoda							
		Unknown Nematode			2		
Clitellata							
	Haplotaxida						
		Tubificidae	1				3
	Lumbriculida						
		Lumbriculidae			1		1
Gastropoda							
	Basommatomorpha						
		Ancylidae (Planorbidae)	2	2	1		
	Neotaenioglossa						
		Pleuroceridae				1	3
Arachnida							
	Trombidiformes						
		Hydracarina			2	7	
Insecta							
	Coleoptera						
		Elmidae		2	10	3	
		Hydrophilidae				1	
	Diptera						
		Ceratopogonidae	1		5		
		Chironomidae	1003	961	735	931	106
		Empididae	4	2	20	5	
		Simulidae					2
	Ephemeroptera						
		Baetidae		12	14	10	
		Caenidae			3		

Cont. Appendix D. Macroinvertebrate taxa Hester-Dendy abundance by site.

Class	Order	Family	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**
Insecta							
	Ephemeroptera						
		Ephemerellidae			2		
		Heptageniidae	58	140	316		5
		Isonychiidae			16		
		Leptohyphidae		29	27	29	1
	Megaloptera						
		Corydalidae			1	1	
	Odonata						
		Coenagrionidae	2		1		
		Corduliidae	3				
Insecta							
	Plecoptera						
		Perlidae	2		3	3	
		Pteronarcyidae	1	1	1	4	
		Taeniopterygidae			13	12	
		Unknown Plecopteran A (Pteronarcyidae?)		2			
		Unknown Plecopteran B (Taeniopterygidae?)		41			
		Unknown Plecopteran C (Capniidae or Taeniopterygidae?)			2		
		Unknown Plecopteran D (Perlidae or Perlodidae?)				1	
	Trichoptera						
		Brachycentridae				3	
		Hydropsychidae	17	516	564	178	16
		Hydroptilidae		24	29	64	
		Leptoceridae	1	1	8	4	
		Polycentropodidae	7	23	10	8	
		Unknown Trichopoteran A (Lepidostomatidae?)				1	
		Unknown Trichopteran B (Hydropsychidae?)		10			

Cont. Appendix D. Macroinvertebrate taxa Hester-Dendy abundance by site.

Class	Order	Family	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**
Malacostraca							
	Amphipoda						
		Pontoporeiidae					1
	Isopoda						
		Asellidae	1				4

Appendix E. Macroinvertebrate taxa kick net abundance by site.

Class	Order	Family	**GR3**	**GR4**
Turbellaria				
		Unknown Turbellarian		1
Clitellata				
	Haplotaxida			
		Tubificidae		5
	Lumbriculida			
		Lumbriculidae		1
Bivalvia				
	Veneroidea			
		Corbiculidae	60	3
Gastropoda				
	Basommatomorpha			
		Ancylidae (Planorbidae)	3	2
	Neotaenioglossa			
		Pleuroceridae		7
Arachnida				
	Trombidiformes			
		Hydracarina	1	
Insecta				
	Coleoptera			
		Elmidae	66	49
		Hydrophilidae	1	
		Psephenidae	10	1
	Diptera			
		Ceratopogonidae	2	1
		Chironmidae	38	
		Simuliidae	1	
	Ephemeroptera			
		Baetidae	68	47

Cont. Appendix E. Macroinvertebrate taxa kick net abundance by site.

Class	Order	Family	**GR3**	**GR4**
Insecta				
	Ephemeroptera			
		Caenidae	6	1
		Heptageniidae	127	59
		Isonychiidae	4	1
		Leptohyphidae	56	9
	Megaloptera			
		Corydalidae	1	
	Odonata			
		Coenagrionidae	1	
		Gomphidae	6	
Insecta				
	Plecoptera			
		Perlidae	2	8
		Pteronarcyidae	2	
	Trichoptera			
		Hydropsychidae	98	10
		Hydroptilidae	16	9
Malacostraca				
	Decapoda			
		Cambaridae	1	

Appendix F. Mussel species abundance for each site surveyed.

	Site Number and Habitat Type							
	GR1	GR2	GR3	GR4	GR5	GR6	GR7	GR8
Species	IMP	IMP	IMP	Flow	Flow	Flow	Pool	Pool
Actinonaias ligamentina				1		1		
Amblema plicata								
Cyclonaias pustulosa				7		1	1	
Cyclonaias tuberculata								
Cyprogenia stegaria								
Ellipsaria lineolata				3				
Elliptio crassidens								
Eurynia dilatata								
Fusconaia subrotunda								
Lampsilis cardium				1	1	2		
Lampsilis ovata				2		2		
Lampsilis siliquoidea								
Lasmigona complanata					1	1	1	
Lasmigona costata								
Leptodea fragilis								
Ligumia recta								
Megalonaias nervosa		3		3		1		
Obliquaria reflexa				9		3	4	1
Plethobasus cyphyus								
Pleurobema sintoxia								
Potamilus alatus			1	7	8	3	15	2
Ptychobranchus fasciolaris								
Quadrula quadrula				8	6	12	2	
Strophitus undulatus				1		1		
Theliderma metanevra								
Tritogonia verrucosa				3	1	1		
Truncilla truncata				1				
Number of mussels collected:	0	3	1	46	17	28	23	3
Number of species collected:	0	1	1	12	5	11	5	2
Sample Time (minutes):	13	15	14	46	28	33	38	30
CPUE (mussels per minute):	0.00	0.20	0.07	1.00	0.61	0.85	0.61	0.10

Note: Imp = Impounded Site, Flow = Riffle/Run Site, Pool = Pool Site

Cont. Appendix F. Mussel species abundance for each site surveyed.

	Site number and habitat type							
	GR9	GR10	GR11	GR12	GR13	GR14	GR15	GR16
Species	Pool	Pool	Flow	Flow	Pool	Flow	Pool	Flow
Actinonaias ligamentina			2			1		
Amblema plicata						1		
Cyclonaias pustulosa			11	2		2		1
Cyclonaias tuberculata								
Cyprogenia stegaria								
Ellipsaria lineolata			1					
Elliptio crassidens								
Eurynia dilatata								
Fusconaia subrotunda								
Lampsilis cardium			4	1		2		
Lampsilis ovata		1	1	2		3		
Lampsilis siliquoidea								
Lasmigona complanata								
Lasmigona costata								
Leptodea fragilis				1	1			
Ligumia recta								
Megalonaias nervosa			7	2	1	4		1
Obliquaria reflexa		1	10	2	6	3		2
Plethobasus cyphyus								
Pleurobema sintoxia								
Potamilus alatus	1	1	14	7	1	4	1	1
Ptychobranchus fasciolaris			2					
Quadrula quadrula		2	19	2	5	4	1	2
Strophitus undulatus								
Theliderma metanevra						1		
Tritogonia verrucosa			11	1	1			2
Truncilla truncata								
Number of mussels collected:	1	5	82	20	15	25	2	9
Number of species collected:	1	4	11	9	6	10	2	6
Sample Time (minutes):	28	11	41	32	17	26	17	24
CPUE (mussels per minute):	0.04	0.45	2.00	0.63	0.88	0.96	0.12	0.38

Note: Imp = Impounded Site, Flow = Riffle/Run Site, Pool = Pool Site

Cont. Appendix F. Mussel species richness and abundance for each site surveyed.

	Site Number and Habitat Type							
	GR17	GR18	GR19	GR20	GR21	GR22	GR23	GR24
Species	Flow	Pool	Flow	Flow	Flow	Flow	Pool	Pool
Actinonaias ligamentina	3			1	6	1		
Amblema plicata					1			
Cyclonaias pustulosa	11		1	7	11	4		
Cyclonaias tuberculata					1			
Cyprogenia stegaria					1			
Ellipsaria lineolata	1			1	1			
Elliptio crassidens				1				
Eurynia dilatata	2			1	1			
Fusconaia subrotunda				1				
Lampsilis cardium	1							
Lampsilis ovata	1		1	2	3	1		
Lampsilis siliquoidea	1							
Lasmigona complanata								
Lasmigona costata						1		
Leptodea fragilis	3				1	1		
Ligumia recta				1	1	1		1
Megalonaias nervosa	5				4	1		1
Obliquaria reflexa	5	1		1	8			
Plethobasus cyphyus						1		
Pleurobema sintoxia	1				1			
Potamilus alatus	6			10	14	3	1	1
Ptychobranchus fasciolaris	1							
Quadrula quadrula	3			4	11	4		1
Strophitus undulatus								
Theliderma metanevra					1			
Tritogonia verrucosa	11			4	4	1		
Truncilla truncata					2			
Number of mussels collected:	55	1	2	34	72	19	1	4
Number of species collected:	15	1	2	12	18	11	1	4
Sample Time (minutes):	54	13	106	40	56	25	28	23
CPUE (mussels per minute):	1.02	0.08	0.02	0.85	1.29	0.76	0.04	0.17

Note: Imp = Impounded Site, Flow = Riffle/Run Site, Pool = Pool Site

Cont. Appendix F. Mussel species richness and abundance for each site surveyed.

	Site Number and Habitat Type		
	GR25	GR26	GR27
Species	Pool	Flow	Flow
Actinonaias ligamentina			
Amblema plicata			
Cyclonaias pustulosa		3	
Cyclonaias tuberculata			
Cyprogenia stegaria			
Ellipsaria lineolata			
Elliptio crassidens			
Eurynia dilatata		1	
Fusconaia subrotunda			
Lampsilis cardium			
Lampsilis ovata			
Lampsilis siliquoidea			
Lasmigona complanata			
Lasmigona costata			
Leptodea fragilis		1	
Ligumia recta			
Megalonaias nervosa	1		
Obliquaria reflexa		2	
Plethobasus cyphyus			
Pleurobema sintoxia			
Potamilus alatus		1	
Ptychobranchus fasciolaris			
Quadrula quadrula			1
Strophitus undulatus			
Theliderma metanevra			
Tritogonia verrucosa		3	
Truncilla truncata		1	
Number of mussels collected:	1	12	1
Number of species collected:	1	7	1
Sample Time (minutes):	20	27	17
CPUE (mussels per minute):	0.05	0.44	0.06

Note: Imp = Impounded Site, Flow = Riffle/Run Site, Pool = Pool Site

Appendix G. Fish taxa and abundance by site.

Order	Family	Species	Common Name	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**	**Total**
Lepisosteiformes									
	Lepisosteidae								
		Lepisosteus osseus	Longnose Gar	5	5	4	4		18
Osteoglossifomores									
	Hiodontidae								
		Hiodon tergisus	Mooneye			3	2	1	6
Clupeiformes									
	Clupeidae								
		Dorosoma cepedianum	Gizzard Shad	21	44	5	2	6	78
Cypriniformes									
	Cyprinidae								
		Campostoma oligolepis	Largescale Stoneroller			7			7
		Cyprinella spiloptera	Spotfin Shiner	3	2	9	56	2	72
		Erimystax dissimilis	Streamline Chub			5	12		17
		Hybopsis amblops	Bigeye Chub			31	9		40
		Luxilus chrysocephalus	Striped Shiner			4	2		6
		Notropis ariommus	Popeye Shiner			20	3		23
		Notropis atherinoides	Emerald Shiner	1	1	2	6	15	25
		Notropis micropteryx	Highland Shiner		6	141	209		356
		Notropis photogenis	Silver Shiner			6	2	1	9

Cont. Appendix G. Fish taxa abundance by site.

Order	Family	Species	Common Name	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**	**Total**
Cypriniformes									
	Cyprinidae								
		Notropis volucellus	Mimic Shiner		3	100	45		148
		Phenacobius uranops	Stargazing Minnow			2	4		6
		Pimephales notatus	Bluntnose Minnow			20	11		31
		Pimephales vigilax	Bullhead Minnow		37	7	10	1	55
	Catostomidae								
		Carpiodes carpio	River Carpsucker		6		2	1	9
		Carpiodes cyprinus	Quillback			2		2	4
		Hypentelium nigricans	Northern Hog Sucker			3	22		25
		Ictiobus bubalus	Smallmouth Buffalo	4	4	6	3		17
		Minytrema melanops	Spotted Sucker	11	5	1		2	19
		Moxostoma anisurum	Silver Redhorse	4	10	1	1		16
		Moxostoma breviceps	Smallmouth Redhorse			7	5		12
Cypriniformes									
	Catostomidae								
		Moxostoma carinatum	River Redhorse			3	5		8
		Moxostoma duquesnei	Black Redhorse				1		1
		Moxostoma erythrurum	Golden Redhorse	7	47	25	39	6	124

Cont. Appendix G. Fish taxa abundance by site.

Order	Family	Species	Common Name	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**	**Total**
Siluriformes									
	Ictaluridae								
		Ictalurus punctatus	Channel Catfish		2	3	5		10
		Noturus eleutherus	Mountain Madtom				3		3
		Noturus miurus	Brindled Madtom	1			1		2
		Noturus nocturnus	Freckled Madtom				1		1
		Pylodictis olivaris	Flathead Catfish		1	1	3		5
Salmoniformes									
	Esocidae								
		Esox masquinongy	Muskellunge		1				1
Atheriniformes									
	Atherinidae								
		Labidesthes sicculus	Brook Silverside			2			2
Cyprinodontiformes									
	Fundulidae								
		Fundulus catenatus	Northern Studfish			1			1
		Fundulus notatus	Blackstrip Topminnow			1			1
Scorpaeniformes									
	Cottidae								
		Cottus carolinae	Banded Sculpin	1		19	17		37

Cont. Appendix G. Fish taxa abundance by site.

Order	Family	Species	Common Name	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**	**Total**
Perciformes									
	Moronidae								
		Morone chrysops	White Bass			1			1
		Morone chrysops x saxatilis	Hybrid			1			1
	Centrachidae								
		Ambloplites rupestris	Rock Bass			1	6		7
		Lepomis macrochirus	Bluegill	7	1	6	3	1	18
Perciformes									
	Centrarchidae								
		Lepomis megalotis	Longear Sunfish	22	19	16	23	2	82
		Lepomis microlophus	Redear Sunfish			1			1
		Micropterus dolomieu	Smallmouth Bass	1		3			4
		Micropterus punctulatus	Spotted Bass	11	5	7	9	5	37
		Micropterus salmoides	Largemouth Bass	1	3	3	2		9
		Pomoxis nigromaculatus	Black Crappie	1					1
Perciformes									
	Percidae								
		Ammocrypta clara	Western Sand Darter		1	2			3
		Etheostoma bellum	Orangefin Darter			1			1

Cont. Appendix G. Fish taxa abundance by site.

Order	Family	Species	Common Name	**GR1**	**GR2**	**GR3**	**GR4**	**NR1**	**Total**
Perciformes									
	Percidae								
		Etheostoma blennioides	Greenside Darter			1			1
		Etheostoma caeruleum	Rainbow Darter	1					1
		Etheostoma nigrum	Johnny Darter			5			5
		Etheostoma zonale	Banded Darter				1		1
		Percina caprodes	Logperch	1		2	3	2	8
		Percina copelandi	Channel Darter			1			1
		Percina evides	Gilt Darter		33	10	66		109
		Percina phoxocephala	Slenderhead Darter	1	2	2	5		10
		Percina sciera	Dusky Darter	1	2	1	3		7
		Sander vitreus	Walleye	1		1			2
	Sciaenidae								
		Aplodinotus grunniens	Freshwater Drum	1	12	7			20
			Native Richness:	22	24	49	39	14	58
			Abundance:	107	252	513	606	47	1525

Appendix H. Stream wetted width, depth, and substrate type.

GR1		Upstream		Middle		Downstream	
Wetted Width (m)		53.1		51		56	
		Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
	LB 1	0.6	Mud	0.5	Mud	0.25	Mud
	LB 2	3	Mud	4.4	Mud	4.5	Mud
	LB 3	4.75	Sand	6.4	Mud	5.7	Mud
	RB 3	6.4	Gravel	6.75	Mud	6.5	Boulder
	RB 2	5	Pebble	3.75	Bedrock	6.15	Mud
	RB 1	1	Mud	0.5	Mud	0.25	Mud

GR2		Upstream		Middle		Downstream	
Wetted Width (m)		54		55		55	
		Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
	LB 1	0.5	Mud	0.5	Mud	0.15	Mud
	LB 2	1.8	Mud	1.5	Mud	2.4	Mud
	LB 3	5	Mud	4.35	Sand	5	Sand
	RB 3	5.75	Boulder	4.35	Mud	5.5	Mud
	RB 2	5.25	Mud	3.5	Mud	5	Cobble
	RB 1	0.4	Mud	0.25	Mud	0.3	Mud

GR3		Upstream		Middle		Downstream	
Wetted Width (m)		57		54		60	
		Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
	LB 1	0.1	Mud	0.5	Mud	0.25	Mud
	LB 2	3.25	Mud	3.25	Mud	3.25	Mud
	LB 3	3.4	Sand	3.35	Sand	3.25	Gravel
	RB 3	3.15	Sand	3.35	Sand	3.15	Sand
	RB 2	3.25	Mud	3.5	Mud	2.75	Sand
	RB 1	0.5	Mud	0.5	Mud	0.5	Mud

Cont. Appendix H. Stream wetted width, depth, and substrate type.

GR4	Upstream		Middle		Downstream	
Wetted Width (m)	56		58		52	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.8	Mud	0.75	Mud	0.8	Mud
LB 2	3.4	Mud	3.9	Mud	3.1	Mud
LB 3	4.75	Mud	4.75	Sand	5.15	Sand
RB 3	5.3	Gravel	5.5	Gravel	3.5	Pebble
RB 2	3.5	Sand	3.7	Mud	1.75	Gravel
RB 1	0.9	Mud	0.9	Mud		Mud

GR5	Upstream		Middle		Downstream	
Wetted Width (m)	50		53		59	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	1	Mud	0.8	Mud	0.8	Mud
LB 2	4.25	Gravel	3.8	Pebble	4.4	Sand
LB 3	4	Sand	4.1	Sand	4	Sand
RB 3	4	Sand	4.3	Sand	4.1	Sand
RB 2	4.25	Sand	2.6	Mud	4.35	Mud
RB 1	0.7	Mud	1	Mud	0.75	Mud

GR6	Upstream		Middle		Downstream	
Wetted Width (m)	63		65		53	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.5	Mud	0.4	Mud	0.1	Pebble
LB 2	1.4	Gravel	1.4	Gravel	0.35	Pebble
LB 3	2.1	Gravel	1.3	Cobble	1.15	Pebble
RB 3	2.4	Gravel	1.75	Pebble	2.25	Pebble
RB 2	2.8	Mud	3.5	Mud	2.5	Pebble
RB 1	0.5	Mud	0.5	Mud	1.75	Mud

Cont. Appendix H. Stream wetted width, depth, and substrate type.

GR7	Upstream		Middle		Downstream	
Wetted Width (m)	52		57.5		54.5	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.75	Mud	0.8	Mud	0.7	Mud
LB 2	2.25	Gravel	2.25	Gravel	1.9	Gravel
LB 3	2.8	Sand	2.8	Sand	2.6	Gravel
RB 3	2.7	Gravel	2.8	Sand	2.8	Gravel
RB 2	2.4	Mud	2.7	Mud	3.3	Gravel
RB 1	0.7	Mud	1	Mud	0.7	Mud
GR8	Upstream		Middle		Downstream	
Wetted Width (m)	58.5		53		55	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	1	Mud	1.9	Mud	1	Mud
LB 2	2.4	Gravel	2.7	Gravel	2.4	Sand
LB 3	2.4	Gravel	2.4	Gravel	2.5	Sand
RB 3	2.2	Sand	2.5	Sand	2.5	Sand
RB 2	2.2	Gravel	2.4	Gravel	2.6	Sand
RB 1	0.65	Mud	0.5	Mud	0.4	Mud
GR9	Upstream		Middle		Downstream	
Wetted Width (m)	5		45.5		50.5	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.7	Mud	0.6	Mud	0.75	Mud
LB 2	2.4	Sand	2.4	Gravel	2.4	Gravel
LB 3	3.4	Sand	3.3	Sand	2.8	Sand
RB 3	3.4	Sand	2.6	Sand	3.3	Sand
RB 2	3.15	Sand	3.7	Sand	2.6	Sand
RB 1	3.3	Boulder	3.5	Boulder	1.4	Boulder

Cont. Appendix H. Stream wetted width, depth, and substrate type.

GR10	Upstream		Middle		Downstream	
Wetted Width (m)	57		52		59	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.85	Boulder	0.6	Mud	0.6	Mud
LB 2	2.4	Pebble	2.4	Gravel	2.3	Pebble
LB 3	2.2	Gravel	2.2	Gravel	1.7	Pebble
RB 3	1.9	Cobble	2.4	Cobble	2	Sand
RB 2	1.7	Mud	1.9	Cobble	2.2	Gravel
RB 1	0.75	Mud	0.4	Mud	0.65	Mud

GR11	Upstream		Middle		Downstream	
Wetted Width (m)	60		62		61	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.4	Mud	0.5	Mud	0.3	Mud
LB 2	2	Gravel	1.9	Gravel	1.8	Gravel
LB 3	2.4	Gravel	2	Gravel	1.8	Pebble
RB 3	2.4	Gravel	1.85	Gravel	1.85	Gravel
RB 2	2.15	Gravel	1.7	Gravel	1.6	Gravel
RB 1	0.7	Mud	0.5	Mud	0.3	Mud

GR12	Upstream		Middle		Downstream	
Wetted Width (m)	42		44		52	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	1.15	Mud	0.4	Mud	0.75	Mud
LB 2	2.5	Sand	3	Sand	1.8	Sand
LB 3	3.85	Gravel	3	Gravel	2.2	Gravel
RB 3	3.25	Cobble	3	Pebble	2.25	Gravel
RB 2	2	Cobble	2.5	Pebble	2.4	Pebble
RB 1	1	Cobble	1	Boulder	1.4	Cobble

Cont. Appendix H. Stream wetted width, depth, and substrate type.

GR13	Upstream		Middle		Downstream	
Wetted Width (m)	54.5		49		40	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.6	Mud	0.9	Mud	0.9	Mud
LB 2	2.1	Sand	2.7	Sand	2.6	Gravel
LB 3	2.15	Sand	2.7	Sand	2.5	Gravel
RB 3	2.7	Gravel	2.7	Pebble	2.5	Gravel
RB 2	1.75	Sand	2.7	Cobble	2.6	Cobble
RB 1	0.6	Cobble	0.7	Cobble	0.85	Cobble

GR14	Upstream		Middle		Downstream	
Wetted Width (m)	61		47.3		31.5	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.7	Mud	0.1	Pebble	0.25	Pebble
LB 2	1.3	Pebble	0.25	Pebble	1.26	Pebble
LB 3	1.1	Gravel	0.65	Pebble	2.25	Pebble
RB 3	1.3	Gravel	1.5	Pebble	2.25	Pebble
RB 2	2	Sand	1.75	Pebble	1.8	Pebble
RB 1	1.25	Mud	1.5	Mud	0.5	Mud

GR15	Upstream		Middle		Downstream	
Wetted Width (m)	43		44		47.8	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	1.75	Boulder	0.65	Boulder	0.8	Bedrock
LB 2	2.3	Cobble	1.9	Cobble	2.3	Sand
LB 3	3.6	Pebble	3.5	Pebble	3.4	Pebble
RB 3	3.15	Sand	3.2	Sand	2.9	Sand
RB 2	2.7	Sand	2.25	Sand	2.5	Sand
RB 1	0.4	Sand	0.25	Sand	0.6	Mud

Cont. Appendix H. Stream wetted width, depth, and substrate type.

GR16	Upstream		Middle		Downstream	
Wetted Width (m)	31.7		59		47	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.5	Boulder	0.5	Boulder	0.6	Cobble
LB 2	2.2	Cobble	1.75	Pebble	2.25	Pebble
LB 3	1	Gravel	2.5	Sand	2	Gravel
RB 3	1.5	Gravel	3.3	Sand	2.6	Sand
RB 2	0.75	Sand	1.1	Gravel	1.9	Sand
RB 1	0.4	Sand	0.6	Mud	1.15	Mud
NR1	Upstream		Middle		Downstream	
Wetted Width (m)	23.6		22		18	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.6	Mud	0.75	Mud	0.75	Mud
LB 2	1.7	Mud	2.8	Mud	3	Mud
LB 3	3.4	Gravel	3.25	Gravel	3.5	Mud
RB 3	3.75	Gravel	3.9	Gravel	2.6	Mud
RB 2	2.4	Mud	1.5	Mud	1.6	Mud
RB 1	1	Mud	1	Mud	1	Mud
NR2	Upstream		Middle		Downstream	
Wetted Width (m)	22		20		20	
	Depth (m)	Substrate	Depth (m)	Substrate	Depth (m)	Substrate
LB 1	0.75	Mud	1.25	Mud	0.75	Mud
LB 2	3.15	Mud	2.9	Mud	2.4	Mud
LB 3	3.5	Sand	3.1	Gravel	3.25	Gravel
RB 3	4	Sand	2.85	Mud	2.6	Mud
RB 2	1.4	Mud	2.4	Mud	1.9	Mud
RB 1	0.75	Mud	1	Mud	1.1	Mud

Note: LB/RB 1 refers to measurements taken closest to the Left/Right bank, with LB/RB 3 being closer to the middle of the stream

Appendix I. Site large woody debris (LWD) presence and bank failure (%).

		Upstream				Downstream			
		LB	RB	Left	Right	LB	RB	Left	Right
Code	Hydrology	Failure (%)	Failure (%)	LWD	LWD	Failure (%)	Failure (%)	LWD	LWD
GR1	Pool	0	50		X	0	0	X	X
GR2	Pool	100	0	X		100	0	X	X
GR3	Pool	0	85		X	75	0	X	X
GR4	Pool	100	0	X	X	90	0	X	X
GR5	Pool	0	75	X	X	0	90	X	X
GR6	Flowing	0	0	X	X	0	0	X	X
GR7	Flowing	0	35	X	X	0	12	X	X
GR8	Flowing	0	0	X	X	40	0	X	X
GR9	Flowing	100	0			85	0		X
GR10	Flowing	0	70	X	X	0	0	X	X
GR11	Flowing	0	0	X	X	70	0	X	X
GR12	Flowing	65	0	X		0	0	X	
GR13	Flowing	32	0	X	X	100	0	X	X
GR14	Flowing	0	30	X	X	0	0		X
GR15	Flowing	0	0		X	0	0		X
GR16	Flowing	0	0		X	0	0	X	X
NR1	Pool	100	100	X	X	100	100	X	X
NR2	Pool	95	100		X	100	100		X