# Assessing the Removal of Jordan's Point Dam:

## Geomorphic, Ecological, and Recreational Impacts

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# Executive Summary:

For many residents of Rockbridge County and the City of Lexington, Jordan's Point dam is regarded as both a historical icon and an important source of recreation on the Maury River. Initially constructed circa 1900 to provide hydropower to the local cotton mill, the spillover dam currently serves no function. In 2007, state officials deemed the structure to be unsafe and in violation of the Virginia Dam Safety Act. Given the dam's risk of failure and high cost of repair, the city opted for removal in June of 2017. However, controversy surrounding the decision persists due to the historical and recreational value of Jordan's Point. Additionally, a distinct lack of dam removal research in Virginia renders the environmental and social impacts partially speculative. As such, the impending removal at Jordan's Point presents a unique opportunity to assess the policy's impacts on local geomorphology, ecology, and recreation.

To best predict potential geomorphic and biological responses to the removal of the dam, we must first understand the current environmental context. This required a comprehensive characterization of the current flow, sediment, and biotic regimes. We then conducted extensive literature reviews of past dam removals to infer how removal may affect these systems. Additionally, we surveyed city and county residents to gauge their opinion on the public policy.

We conclude that immediately following the breach, velocity in the impoundment (the ~1 mile long stretch of river immediately upstream of the dam) will increase as the obstacle is removed. To compensate, the water level will drop by an average of 3 to 4 feet. This reduction in area will differ between runs, riffles, and pools and is therefore dependent on channel sinuosity. The increase in velocity will mobilize fine-grained material within the impoundment, but the potential for a rapid sediment "wave" or translation is unlikely given the gravel bedload. Instead, coarser sediment will erode in place. Additionally, the rise in velocity will cause the water temperature around Jordan's Point to cool between 0.5 and 2 degrees Fahrenheit, a minimal change for most biota. A rapid will form at the knickpoint, a drastic change in channel elevation (currently at the site of the dam). Over the span of years to decades, this knickpoint will migrate upstream and decrease in height as the impounded channel incises; erosion of the riverbed should not exceed 4 feet. Throughout this process, the bed's slope will steepen by approximately 45%. The channel will widen as the elevated velocity erodes the banks and causes them to fail, a

process known as slumping. This erosion should persist until upstream and downstream channels are homologous and, if these changes are significantly profound, the active floodplain may shift towards the river once banks stabilize.

These changes to streamflow and channel morphology will impact the Maury River biota. Dam removals are a rapid disturbance to biota and result in a shift from a lentic (slow-moving water) to lotic (fast-moving water) habitat (Stanley and Doyle 2003). Since this dam has altered the fluvial system for over 100 years, the biotic regime has adapted to the lentic conditions within the impoundment. Over time, the diversity and abundance of riparian vegetation, macroinvertebrates, and fish populations near the dam will increase as the stream establishes a new geomorphic equilibrium. More specifically, macroinvertebrate communities should recover after one year, especially if sediment erosion is minimized (Carlson and Donandi 2018, Stanley et al. 2002). After five years, habitat quality and fish abundance will recover (Kanehl et al. 1997).

The reduction in water level will undoubtedly impair flat-water recreation near Jordan's Point during low flows. As such, taxpayers will likely feel a loss in their recreational opportunities on the Maury River. To determine the locals' preferences regarding removal, an analysis was conducted using survey data collected at supermarkets in the Lexington area. Considered preferences included: no removal of the dam, improvement of current facilities at access points along the river, creation of new access points, and removal with no other improvements or changes. The majority of survey participants advocated for the installation of new access points as well as the improvement of current facilities along the Maury. This response was likely due to the excessively high cost of dam repair.

We believe that a full removal of the Jordan's Point dam, the most cost effective approach, will restore the Maury's natural geomorphic regimes and consequently enhance biodiversity. We recommend that the city and DGIF adhere to the current project schedule and breach the dam in the fall.  During dam removals, lower discharges are essential in minimizing erosion as well as adverse impacts to biota. Additionally, we recommend that the DGIF install flow deflection structures prior to removal to mitigate bank failures. Following removal, the DGIF should plant vegetation along the newly exposed banks to bring the system to equilibrium.

Native plant species like sycamore and river birch are preferable due to their benefits to local biota and water quality. The DGIF should conduct frequent ecological and bathymetric surveys to ensure a full recovery of the fluvial system. We highly recommend that the city and county increase and/or improve access points along the Maury River to preserve its recreational use and appease taxpayers.

## Introduction:

For centuries, dams of various operations and sizes have been constructed across the United States to provide irrigation, drinking water, hydroelectric power, and/or flood control. Although many of these structures once yielded great benefits to local economies and public health, nearly "half of the nation's roughly 85,000 known dams no longer serve their intended purposes" (Lovett 2014). Given recent advancements in water treatment and hydroelectric generation, run-of-river dams are particularly impractical. These structures, which are typically low-head (less than 15 feet tall), do not store water but impede streamflow nonetheless. As an obstruction within the channel, spillover dams slow the river's velocity and yield deep, voluminous reservoirs upstream (i.e. impoundments). Such changes to the river's hydrology often alter water temperature, inhibit sediment transport, and impair aquatic life. Additionally, run-of-river dams tend to produce dangerous hydraulics at their base; coined hydraulic rollers, these forceful recirculations of water pose severe drowning hazards to swimmers. One study estimates that "since the 1950s, at least 441 people have died at 235 low-head dams" in the United States ("Hidden dams" 2015). As the maintenance costs and drowning hazards of spillover dams grow increasingly well-known, the removal of these antiquated structures is becoming a commonplace means of cost minimization.

One such removal is scheduled to occur in October of 2018 in Lexington, VA. For many residents of the small, southern town in Rockbridge County, Jordan's Point dam is proudly regarded as both a historical icon and an important source of recreation on the Maury River. Though the dam was constructed circa 1900 to provide hydropower to a local cotton mill, the low-head, spillover dam currently serves no function. In 2006, the death of a resident within the dam's hydraulic rollers prompted citizens to question its safety and continuation. A year later, state officials deemed the dam to be in violation of the Virginia Dam Safety Act (Howard-Cooper 2017). Given its risk of failure, the structure must be removed or repaired. In hopes of restoring the Maury's natural flow regime and ecological integrity, the Virginia Department of Game and Inland Fisheries offered to pay for the removal of the dam, a $190,000 operation (Lexington City Council 2017). In contrast, repair would cost the city between $2.5 and $3 million. Given that the county has no legal claim to the dam, the decision was up to the Lexington city council and, to a lesser extent, the residential taxpayers.

As of June in 2017, the city opted for removal. However, controversy surrounding the decision persists due to the historical and recreational value of Jordan's Point. Although there has been ample dialogue between the city council and local residents during town hall meetings, a distinct lack of surveying fails to account for the preferences of the myriad of citizens not in attendance. Additionally, a deficit of dam-related research in Virginia renders the environmental and social impacts partially speculative. As such, the impending removal at Jordan's Point presents a unique opportunity to develop a case study. This project aimed to characterize the Maury's current geomorphic and biological conditions so as to extrapolate a probable system response following removal. More specifically, we studied the current flow, sediment, and ecological regimes. These predictions, in conjunction with a survey of citizens' preferences, were used to formulate recommendations for the removal of the dam and the preservation of recreational opportunities on the Maury River.

# Methods:

## Geomorphology:

*Flow Regime:*

There is currently no USGS stream gauge on the Maury near Lexington. Given the lack of readily-available hydrologic data, we obtained daily discharge values from the Buena Vista gauge and then normalized by drainage area to calculate an approximate streamflow record for Jordan's Point. Using the USGS StreamStats database, we acquired basin characteristics (such as lithology, land-use, and soil permeability) for these two catchments; basin homogeneity would lend validity to the normalization approach and thus ensure the accuracy of our results. Discharge data was averaged by year since 1939 to determine mean annual flow at Jordan's Point. 25th and 75th percentiles were calculated to establish thresholds between wet and dry years. Additionally, we calculated average monthly discharge starting in 2001 to discern seasonal variations.

In the fall of 2017, we deployed seven HOBO loggers in the reach between Bean's Bottom and the dam to observe longitudinal variations in water temperature. Significant discrepancies between upstream and downstream loggers would suggest that the dam impairs the natural thermal regime within the impoundment. Temperature was logged every fifteen minutes between September 16th and October 26th.

*Sediment Regime:*

To determine average grain size (d50), we sampled the bedload in the riffle just below the dam, in the upper impoundment, and in a reference reach further upstream. Samples were retrieved through wading and shoveling. We sieved the samples to differentiate between grain sizes, and weighed each size to determine its frequency by bulk weight. Minimum sieve size was 0.063 mm. A gravelometer was used to measure sediments larger than 12.5 mm.

We referred to a DGIF topographic map to visualize channel morphology. Using the map's 2 foot contour intervals, we calculated the slope of the impoundment and created two channel cross sections (one above and one below the dam). We then used the cross sections to calculate channel area, wetted perimeter, and hydraulic radius at both transects. All sample sites are shown in Figure 1.

To conclude our approach, we consulted the primary literature to examine how rivers of a similar mean annual discharge and d50 grain size responded to the removal of a low- head, spillover dam.

**Ecology:**

*Riparian Vegetation:*

In fall 2017, riparian vegetation abundance was identified using the point-intercept method along the banks of the Maury River in the impoundment (Tucker and Fields 2017). 17 invasive species were identified.  We compared the two most abundant invasive species with the native plants that will be planted to revegetate the banks to understand the predicted response for riparian vegetation (Campbell 2017).

*Macroinvertebrates:*

Using the aquatic ecology classes' measurements of macroinvertebrates, we compared stream health, EPT taxa, functional feeding group distribution, and species richness (Horan and Carmody 2017). These measurements were taken in the first riffle below the dam to understand how the dam impacts macroinvertebrates downstream. Budget and time constraints rendered our upstream sampling efforts unsuccessful.

*Fish populations:*

Smallmouth bass and carp are some of the most studied fish in the context of dam removals. As such, they act as a good models to predict the impact on similar fish populations that prefer lotic habitat, like smallmouth bass, or lentic habitat, like carp (Kanehl et al. 1997). In addition to the abundance of information, smallmouth bass are some of the most sought after and prized fish in the Maury River, therefore, we focused our analysis on this species to understand how the dam removal will impact fishing opportunities by Jordan's Point (DGIF 2018).

To understand the impact of the dam on smallmouth bass, we utilized the aquatic ecology class' telemetry radio tracking of smallmouth to assess habitat preference (Ross and Wang 2017). Fish were tagged then reintroduced either upstream or downstream of the dam and subsequently recaptured along the Maury; distance from the dam was recorded to calculate displacement. Also, using the primary literature, we categorized Maury River fish species based on habitat preference to understand the predicted influence of the dam removal on each fish species.

**Recreation:**

*Survey Construction:*

We constructed an oral survey designed to discern the preferences of residents within the city of Lexington as well as Rockbridge County. A "damage schedule" would be best for reflecting community preferences because they can be based on "more easily obtained choices of the relative values of various losses without requiring people to assess such impacts in monetary terms" (Chuenpagdee et. al. 2001). Our "damage schedule" compares four different scenarios: No Removal, Removal with Improvements to Current Access Points, Removal with Construction of New Access Points, and Removal with No Changes. These four scenarios were described and their relative values were assigned based on cost estimations found in literature from the Lexington City Council minutes and VDGF as well as databases providing average costs of facility/parking construction (City Council Agenda 2017*; Floyd et al. 2015;* Parking Facility Layout and Dimensions 2018).

*Survey Administration:*

If the city of Lexington incurs any dam-related costs, they will be redistributed to all residents via taxes but not to any specific subgroup such as recreators of the Maury River. Therefore, we administered the survey at locations that attracted all groups of people. Large grocery stores were the best place to administer the survey due to high customer volumes as well as an even representation of subgroups (theoretically). Prior to administering the survey, we obtained the consent of each participant and ensured they were at least eighteen years of age. While completing the survey, participants were given attribute descriptions for four separate scenarios and were then asked to compare each pair of scenarios and indicate their preference (Appendix 1). We used this conceptual framework to indicate locals' prioritization between the different scenarios. Table 1 depicts how the four scenarios were presented to each participant, and the scenario costs can be found in Table 2. We recorded each participant's preferences and then calculated the total number of times each choice was preferred over the others and this was converted into a percent of the total number of times a choice could have been preferred. This enabled us to create a preferential ranking system which was subsequently used to formulate recommendations for the city and county as to how best preserve the river's recreational opportunities.

# Results:

**Geomorphology:**

*Flow Regime:*

As seen in Table 3, the Jordan's Point catchment is sufficiently homologous with the larger BV basin in regards to its geology, land-use, and permeability, thereby lending credence to the normalization analysis. Its results indicate that the Maury River near Jordan's Point exhibits a mean annual discharge of approximately 515 cubic feet per second. As seen in Figure 2, this value fluctuates between "wet years" and "dry years" at discharges greater than 600 or less than 390, respectively. Wet and dry years are generally bounded by stable, intermediate mean annual flows. Figure 3 illustrates the seasonal trends of streamflow at Jordan's Point; high flows occur primarily in the winter and spring whilst fall and summer are dominated by low flows. More specifically, spring features the highest discharges (~800 cfs) while summer bears the lowest (~260). Such a pattern is unsurprising given the seasonal distribution of precipitation inherent to humid regions.

Mean daily water temperature is plotted in Figure 4. Results indicate that mild warming within the impoundment is probable; this observation is most pronounced between 9/27 and 10/2. Figure 5 provides a more precise perspective, for it depicts differences in temperature between adjacent loggers. Water near Jordan's Point is, on average, 0.7 degrees F warmer than upstream. $\Delta T$ at all other sites is far lower.

*Sediment Regime:*

The results of the bulk weight analysis are shown in Table 4 and Figure 6. Of the three sample sites, the impoundment exhibits the lowest grain sizes with a d50 of 51.14 mm. Its bedload is therefore classified as a coarse gravel. Mean grain sizes below the dam and within the reference reach are slightly larger and classified as cobbles. Fine sediments (i.e. sands and silts) are relatively scarce at all sites, but are most prominent within the impoundment (~7% less than 1 mm).

As seen in Figure 7, the dam produces discernible discrepancies in channel morphology. The impounded channel is narrower and deeper compared to the relatively broad and shallow downstream reaches. This is also reflected in the hydraulic geometry results shown in Table 5.

**Ecology:**

*Riparian Vegetation:*

Figure 8 shows distribution of vegetation on the banks of the Maury River by Jordan's Point (See Appendix Table 2 for full list of common species). As reported, 25% of the riparian vegetation is classified as invasive species and only 7% are common local species. Figure 9 shows Japanese stiltgrass (*Microstegium vimineum*) and Chinese yam (*Dioscorea polystachya*) are the most abundant species along the banks. Invasive species outcompete native species and will therefore be a management issue for the DGIF post-dam removal as new banks are exposed.

Table 6 shows comparisons between native and invasive vegetation for many parameters to understand which species will most likely be the primary colonizers of the banks. Although these species are similar, it is important to plant the native species such as American sycamore and river birch to increase biodiversity, control erosion, and create habitat for juvenile fish.

*Macroinvertebrates:*

Table 7 shows the results from the macroinvertebrate stream health survey in the first riffle below the dam. Stream health was fairly good at 85.8/100 and species richness score was high at 95.5/100. However, sensitive macroinvertebrates such as EPT abundance was low for this stream system; EPT taxa was 13, receiving a fair score for water quality range (USDA). Also, Figure 10 shows the disproportionally high abundance of the functional feeding group (FFG) scrapers compared to low abundance of collectors and filterers.

*Fish populations:*

Table 8 shows the results of the smallmouth bass radio telemetry tracking; given the large amounts of displacement following reintroduction, we can conclude that the dam creates unsuitable habitat for the smallmouth bass and similar lotic species.

Table 9 shows the fish that will benefit, suffer, or not be impacted by the dam removal. Fish that will benefit prefer lotic habitat with clear, cold, fast-moving water with natural riffle/run patterns. In contrast, fish that will suffer prefer lentic habitat with turbid, slow-moving water in a pool. Neutral fish can thrive in both lentic and lotic habitats.

**Recreation:**

*Survey Results:*

Survey results indicate that ~76% of participants advocated for the dam's removal (Figure 11). However, the majority of this subgroup felt that the city of Lexington should subsequently take action to preserve recreational opportunities along the Maury. More specifically, 35% of participants believed the city should install new access points whereas the other 30% advocated for the improvement of current facilities. Additionally, approximately 24% preferred the dam stay as is. The smallest subgroup, 11%, opted for removal with no additional changes.

## Discussion:

**Current Conditions:**

*Geomorphology:*

Given our results, we conclude that the Jordan's Point dam yields profound impacts on the Maury's hydrology and geomorphology. As an obstruction within the channel, the dam inherently reduces velocity in the impoundment. To compensate, the upstream water level rises and cross-sectional area increases. The rise in the river's area has generated the significant discrepancies in channel morphology observed in Figure 7, for it has carved out a deep, voluminous channel through more than 100 years of erosion. The impounded, slow-flowing water experiences mild warming (~0.7 degrees F) due to the lack of turbulence, thereby enabling solar insolation to heat the surface prior to mixing. The absence of cold-water tributaries near Jordan's Point amplifies this warming. Additionally, the reduced velocity promotes deposition of fine sediment within the impoundment; approximately 7% of the upstream bedload is sand and silt compared to <1% in the reference reach. That being said, this proportion of fine-grained material is fairly minimal and thus it is safe to conclude that there is little to no sediment trapping behind the dam. Despite the dam's hindrance, the velocity at Jordan's Point is presumably sufficient in entraining most sands and silts and transporting them further downstream as evidenced by the intermediate grain sizes observed below the dam. If significant fine-grained trapping did occur, downstream d50 would be greater and nearly equivalent to that of the reference reach. Furthermore, the transport of fine sediment is facilitated by the modest size of Jordan's Point dam; during high flows and storm surges, the structure is mostly (if not completely) submerged and most sediment is flushed downstream (Csiki and Rhoads 2010).

The dam is considered a knickpoint, a geomorphic term used to describe a significant change in streambed elevation. The river's potential energy is highest at the knickpoint. But when the cascading water spills over the dam and flows downstream, this is translated into kinetic energy. As a result, the Maury's velocity and erosional capacity intensify, thereby reducing the water level and promoting channel widening downstream (Figure 7). At the base of the dam, the increase in velocity and turbulence produce hydraulic rollers, forceful and hazardous recirculations of water (Csiki and Rhoads). As seen in Figure 6, the downstream bedload is relatively coarse due to a rise in sediment transport capacity, a byproduct of the accelerated streamflow. The coarse substrate in conjunction with the aforementioned decrease in water level accounts for the presence of riffle-run patterns below the dam.

*Ecology:*

Currently, the most abundant invasive species by Jordan's Point dam are Chinese yam (*Dioscorea polystachya*) and Japanese stiltgrass *(Microstegium vimineum*). These invasive species are able to outcompete natives due to their quick growing speed, rapid seed dispersal, and high tolerance for sunlight and soil moisture.

Macroinvertebrates communities are helpful bioindicators for overall stream health because they have limited mobility and are susceptible to small changes in environmental conditions (Horan and Carmody 2017). The downstream stream health index was fairly high but low EPT taxa and high scraper abundance are two indicators that the dam currently creates an unsuitable habitat for all macroinvertebrates (Horan and Carmody 2017).

The dam diminishes the water quality for more sensitive orders of macroinvertebrates. There is a low amount of Ephemeroptera, Plecoptera, and Trichoptera orders (EPT taxa) relative to the total amount of macroinvertebrates (Carlson and Donadi 2018). These sensitive macroinvertebrates cannot survive as well downstream of the dam because the structure creates an unsuitable habitat. Additionally, scrapers are the dominant functional feeding group (FFG) below the dam (Horan and Carmody 2017). Currently, the dam inhibits the downstream transport of organic matter due to the low velocity; organic matter likely drops from the suspended load and settles to the streambed. This restricts a major food source for other FFG like collectors and filterers.

Lastly, the inverse relationship between carp and smallmouth bass is the most widely studied impact of dam removal on fish populations; due to the abundance of information, they act as a good model for fish that prefer lotic habitat (smallmouth bass) or lentic habitat (carp) (Kanehl et al. 1997). Currently, the dam creates unsuitable habitat for smallmouth bass as shown by Ross and Wang;  all smallmouth bass tracked via radio telemetry traveled away from the dam after reintroduction into the stream (Ross and Wang 2017, Tullus et al. 2014). Fish downstream of the dam moved twice as far away from the dam than fish upstream of the dam, indicating that downstream ecosystems are more negatively impacted by the dam and will benefit from the removal. Additionally, fish are unable to travel past the dam due to the broken fish ladder; this separates metapopulations upstream and downstream and restricts habitat range (DGIF 2017, Ross and Wang 2017). Currently carp's abundance and destructive feeding habitats negatively affect the entire ecosystem such as uprooting vegetation, thereby increasing turbidity and erosion. Other macroinvertebrates and fish populations cannot thrive under high levels of turbidity.

*Recreation:*

The impoundment upstream of Jordan's Point dam consists of a ~1 mile stretch of traveserable and accessible flat water. As such, the dam provides a plethora of recreational opportunities for citizens such as kayaking, canoeing, and tubing. But given the impaired streamflow and unfavorable habitat conditions, fishing is generally poor above Jordan's Point. The dam creates an unsuitable habitat for lotic species due to the restricted flow, increased turbidity, and disconnect between upstream and downstream populations. This reduces the prevalence of smallmouth bass, a charismatic and relatively prized trophy fish.

**Post-Removal Predictions:**

*Geomorphology:*

When the dam is breached, velocity within the impoundment will instantaneously increase as the obstacle is removed. To compensate, the water level will drop by an average of 3 to 4 feet, the difference between upstream and downstream depth (Figure 7). This reduction in cross sectional area will be distributed between runs, riffles, and pools and is therefore dependent on channel sinuosity. More specifically, drops in water level will be most pronounced in reaches with a linear channel (i.e. where riffles will form). In contrast, pools will develop at river bends where changes in water level will be minimal. Figure 13 illustrates the probable distribution of these channel patterns. Additionally, the rise in velocity will induce turbulence within the impoundment. As such, mixing will become more effective and water temperature at Jordan's Point will cool between 0.5 and 2 degrees Fahrenheit.

Upon removal, the increase in velocity will mobilize fine-grained material within the impoundment, but the potential for a rapid sediment "wave" or flux is unlikely given the coarse bedload and lack of sediment trapping. Prior research suggests that gravel-bedded systems seldom exhibit translation (wave) pulse behavior but rather demonstrate dispersion, a pulse "characterized by diminishment of a longitudinally stationary [mound of sediment] and lengthening of the distance between edges." (Pace et. al 2016) In other words, the post-removal spike in velocity will prove insufficient in transporting the coarse bedload, which may erode in place over time. Even so, initial changes to the sediment regime will be defined by a mild increase in d50 grain size near the dam as sands and silts (a mere 7% of the bedload) are flushed downstream in a matter of hours to days (Burroughs et. al. 2009). Based off prior research, we can safely conclude that these sediments contain minimal hazardous chemicals and that there is a low potential for a toxic sediment release (Fox 2009).

The aforementioned changes to water velocity and cross sectional area will initiate channel adjustments as the shallower, faster Maury begins to erode a new channel. These adjustments, which typically adhere to a coherent geomorphic sequence, will operate on the span of years to decades (Pizzuto 2009). When the structure is removed, a waterfall will immediately form at the knickpoint. Due to its high velocity and immense kinetic energy, the knickpoint will undergo intense erosion. Over time, this knickpoint will migrate upstream and decrease in height as the impounded channel incises. Throughout this process, the bed's slope will steepen by approximately 45% (Table 5). Knickpoint retreat is a common geomorphic process in which an adjusting channel progressively erodes its riverbed so as to reduce the elevation gradient imposed by the former dam. The impounded channel will incise until upstream and downstream bed elevations are comparable; as such, vertical erosion should not exceed 4 feet (Figure 7). The channel will then adjust horizontally. Elevated velocities will erode the banks, steepen them to a critical angle, and induce failure, a process known as slumping. The channel will continue to widen via slumping, and the influx of bank sediment will be transported downstream. Banks on the outside of meanders are particularly prone to fail. This lateral erosion should persist until upstream and downstream channels are morphologically homologous. Over time, the new channel will deepen and widen to achieve equilibrium with downstream reaches, but we must emphasize that it will still be shallower and narrower *relative* to the former impoundment. If these geomorphic adjustments are significantly profound, the active floodplain may shift towards the river once banks stabilize and riparian vegetation proliferates.

*Ecology:*

Dam removals are a short-term disturbance as the system shifts from a lentic to lotic habitat (Stanley and Doyle 2003). Since this dam has been influencing the river for over 100 years, the habitat and biota have adapted to the slow-moving water behind the impoundment. As a result, after the dam is removed there may be an initial decrease in biota, but over time the habitat and biota will fully recover as the stream is restored.

As the water levels lower after the dam removal, there will be new nutrient rich habitat available once the new banks are exposed (Stanley and Doyle 2003). Primary colonizers for this area are usually invasive species, such as the Chinese yam *(Dioscorea oppositifolia*) and Japanese stiltgrass *(Microstegium vimineum*) (Tucker and Fields 2017). Both of these invasive species are incredibly tolerant and produce and spread seeds easily; this allows them to quickly outcompete the native species (Tucker and Fields 2017). Japanese stiltgrass produce up to 1,000 seeds and disperse seeds by water and wind; seeds can survive for five years in the soil (Rutgers 2014). Chinese yam is a tall vine that allows it to outcompete other plants for sunlight (Missouri Conservation 2010). They also disperse seeds by water. Controlling these invasives with herbicides has been the most successful method for removing large populations, however, is not recommended here because this would pollute the Maury River, the drinking water source for Lexington, VA (Missouri Conservation 2010). Both of these species are perennials and although they die down during fall and winter, they quickly reproduce and grow again during spring and summer (Missouri Conservation 2010, Rutgers 2014). These factors and their abundance by Jordan's Point make likely candidates for first colonizers, especially on the new stream banks.

However, the Virginia DGIF is partnering with the James River Association to revegetate the newly exposed banks during the first dormant season post-dam removal (March - April 2019) (City Council 2018). They will plant native species such as American sycamore (*Platanus occidentalis L*.) and river birch (*Betula nigra*) to reduce the likelihood of invasive species and erosion as well create habitat for juvenile fish (Campbell 2018, Edwards et al. 1983). These are both strong primary colonizers that will help reduce the impact of invasive species because they utilize the river for seed dispersal and are fast-growing tall strong trees (Neson 2002, Sullivan 1993). Additionally, the native species have deeper and stronger root systems than the invasive species, therefore, native species would stabilize banks thus creating more habitat for juvenile fish. Stabilization of banks also reduces sediment erosion influence on downstream macroinvertebrate communities, which would then propagate up the food chain to larger fish populations. However, they require more direct sunlight than the invasive species, therefore for successful revegetation of the banks, they must be planted in the dormant season before the invasive species are able to colonize the banks.

If sediment erosion is minimized through revegetation of the banks, macroinvertebrates should recover within a year (Stanley et al. 2002). Also, dam removals are shown to increase EPT taxa and, therefore, overall stream health (Carlson and Donadi 2018). Once the dam is removed, the upstream and downstream macroinvertebrate populations will be connected, and organic matter will not be blocked by the dam. This connection and influx of organic matter in the water will increase FFG like collectors and filterers to created a more heterogeneous macroinvertebrate community. This increase in stream health and macroinvertebrate community structure also benefits up the food chain to fish populations.

Five years after the dam removal, habitat quality and lotic fish species abundance recover (Kanehl et al. 1997). Smallmouth bass populations and similar lotic species abundance increase after dam removals as the habitat is restored to their preferred habitat of clear quick-moving water with a riffle/run pattern (Edwards et al. 1983). Metapopulations will be connected, which will increase habitat range for smallmouth bass. Additionally, revegetation of the banks will create new habitat for juvenile smallmouth bass and other similar fish (Edwards et al. 1983). Juveniles prefer low velocity water near a current and live mostly in small crevices; these conditions will be available by the newly revegetated banks. However, common carp and similar lentic species abundance decreases after dam removal due to the increased velocity of water (Kanehl et al. 1997). Yet, a decrease in carp abundance can improve the entire ecosystem as they create unsuitable habitat for native species that thrive in lotic habitats (DPI 2010).

*Recreation:*

Given the aforementioned reduction in water level and the reemergence of riffle-runs, flat-water recreational opportunities near Jordan's Point will consequently be altered. As is the case farther upstream, the river may not be easily accessible during low flow events. However, activities such as kayaking will still be possible during higher flows (bearing the safety concerns in mind). Additionally, the emergence of a rapid at the knickpoint may present a recreational opportunity for some fast-water kayakers.

However, fishing opportunities should improve dramatically after fish populations recover. As previously stated, sportfish such as smallmouth bass and other lotic species will benefit from the increases in water velocity, riffle prevalence, and river connectivity. This will enable fishermen to expand their targeting locations all along the Maury as habitat improves and fish populations reconnect.

## Recommendations:

We believe that a full removal of the Jordan's Point dam, the most cost-effective approach, will ultimately restore the Maury River's natural flow, sediment, and biotic regimes. Though initial geomorphic and hydrologic adjustments may pose a threat to biota and riverside properties, preemptive action by the city council and the DGIF should mitigate these risks. For example, we stress that the DGIF adhere to the current project schedule and breach the dam in October, when flows are low and recreation is sparse. If the project falls behind schedule, the DGIF should opt to wait until the summer or fall of 2019. Lower discharges are essential so as to alleviate excess erosion and potential sediment pulses. Downstream biota, specifically macroinvertebrates that are particularly vulnerable due to their inability to migrate, will recover quicker at lower sediment loads. Additionally, an October removal will hamper the growth of invasive species such as the Chinese yam and Japanese stiltgrass.

Prior to removal, we recommend that the DGIF install flow deflection structures within the impoundment to mitigate slumping. Specifically, these structures should divert flow away from erodible and failure-prone banks on the outside of meanders. Additionally, the DGIF may armor the banks with bedded river cobbles to further control erosion. Cobbles should be greater than 3.5 inches (d90 grain size) so they are not transportable at base flow, and should be retrieved from the bedload. Local, in-situ sediments are preferable to riprap because while the former are natural components of the sediment regime that facilitate gradual adjustments, the latter are excessively non-erodible, confine the channel, and merely deflect erosion downstream. In the context of bank stabilization, inaction would prove highly detrimental. For example, the removal of a 15-foot hydroelectric dam in 1974 prompted severe erosion at the confluence of the Maury near Glasgow, VA. With minimal bank stabilization, the channel "eroded laterally more than 100 feet … and [took] roughly 9,384 tons of soil downriver to the James and eventually to the Chesapeake Bay" ("Maury River" 2016). Failure to take preemptive action at Jordan's Point would assuredly lead to local property damage as well as environmental degradation farther downstream.

Immediately following the dam's removal and the subsequent reduction of water level, the DGIF should plant vegetation along the newly exposed banks to bring the system to equilibrium. The revegetation will be most successful if native species are planted during the dormant season when invasive species are not a threat to the system. Also, revegetation of all exposed banks will ensure successful erosion control for vulnerable riverfront property. Strong native species such as river birch and American sycamore are preferable due to their capacity for early colonization and ability to compete with invasive vegetation. The establishment of a riparian buffer is effective for erosion control, ecological restoration, and water quality improvement.

Additionally, we recommend that the DGIF survey the site several times per year to track progress of channel evolution. Geometric parameters (wetted perimeter, area, etc.) can be used to constrain channel adjustments. Vegetation, macroinvertebrate, and fish populations should be continually monitored by the DGIF to ensure a full recovery of the biota. Surveying should be done in collaboration with W&L students to foster local involvement and provide educational opportunities. Frequent surveying will enable the DGIF to operate proactively in the event of an adverse system response.

To preserve the recreational potential of the Maury River, we recommend that the city of Lexington increase the number of and improve access points along the river to respect citizens' preferences. This will alleviate the subsequent loss of flat-water recreation at Jordan's Point.

Figure 13 shows our recommendation for proposed new access points and improvements to current facilities. Installation will cost a total of $86,000 per site whereas improvement will cost an average of $44,000 per site. For simplicity, these costs were presented to survey participants as a one year tax. In reality, they should be distributed over several years to decrease the financial burden on taxpayers.

Given the time and budget constraints associated with this project, there were some limitations that may be amended by future research. For example, subsequent projects may address more aspects of the fluvial system such as bank soils, the suspended load, or mean water depth. Future researchers should refine our data collection and perform more comprehensive surveys of the vegetation, macroinvertebrates, and bathymetry. Following the dam's removal in the coming school year, W&L students should conduct a follow-up study to assess how the local geomorphic and biotic regimes genuinely responded. This scientific research could be used in conjunction with an economic survey designed to assess local citizens' satisfaction with the new and/or improved recreational access points. When coupled with this capstone paper, such a research project would serve as a comprehensive and reliable case study for future proposed dam removals throughout the country.

# Figures:

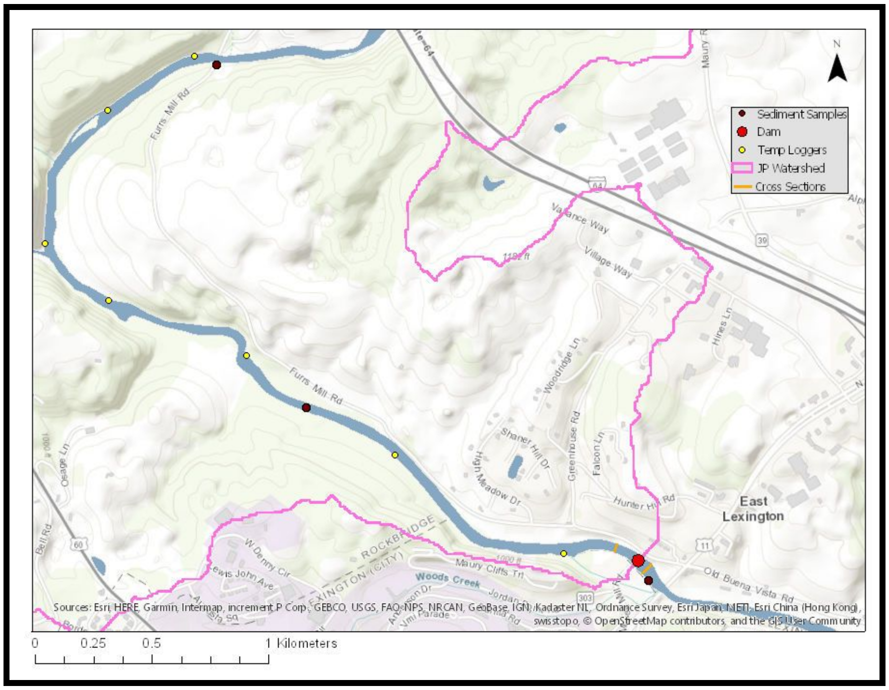


**Figure 1: Site map denoting bottom boundary of the Jordan's Point catchment as well as data collection locations.**

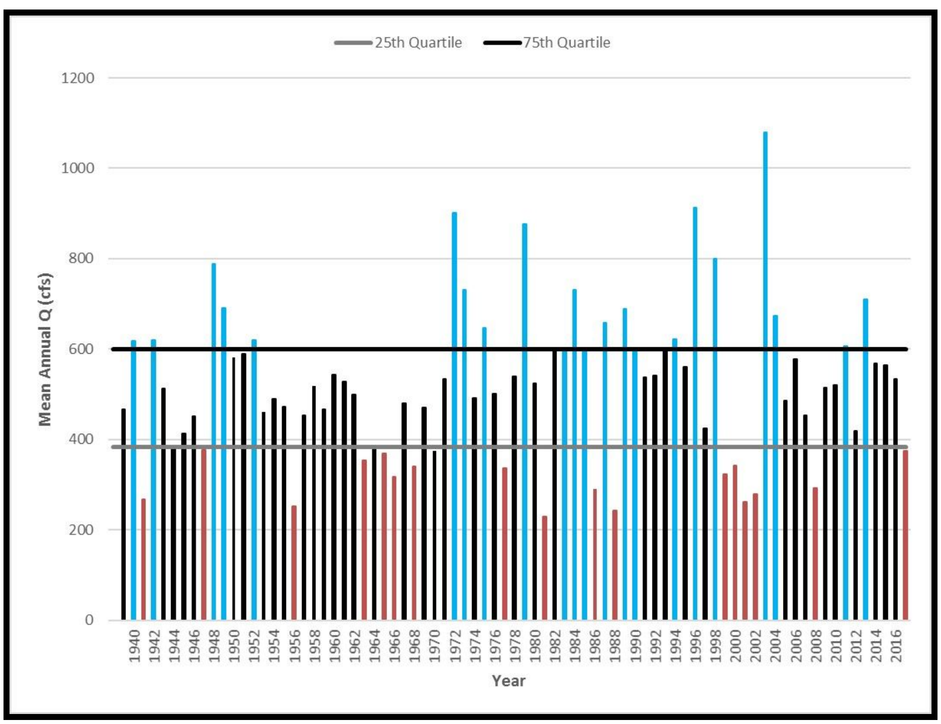


**Figure 2: Historical streamflow record at Jordan's Point.**
Blue and red bars indicate wet and dry years respectively.

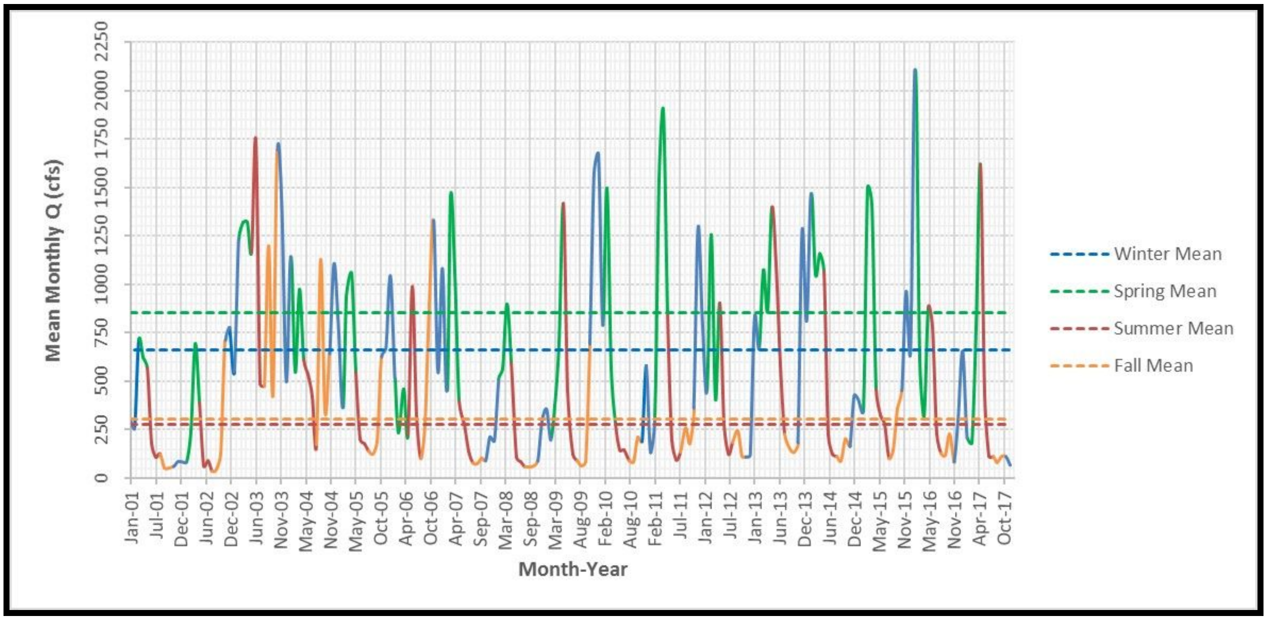


**Figure 3: Seasonal streamflow record.**
Colors correspond to respective seasons.

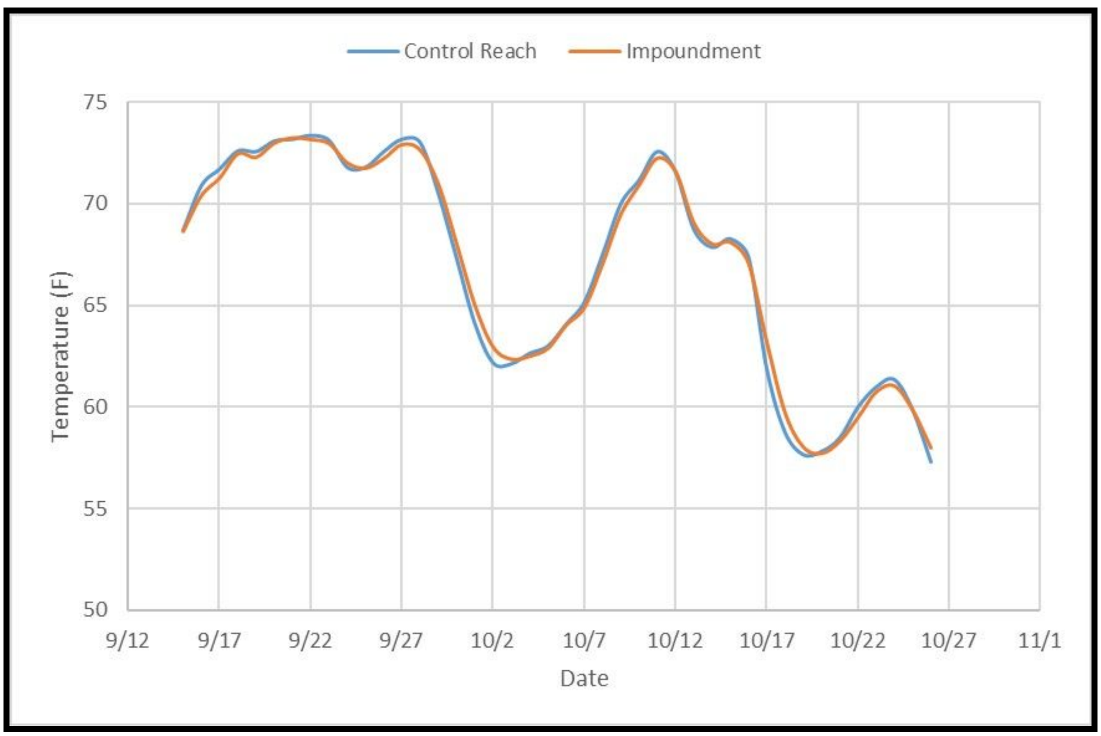


**Figure 4: Average daily water temperature.**

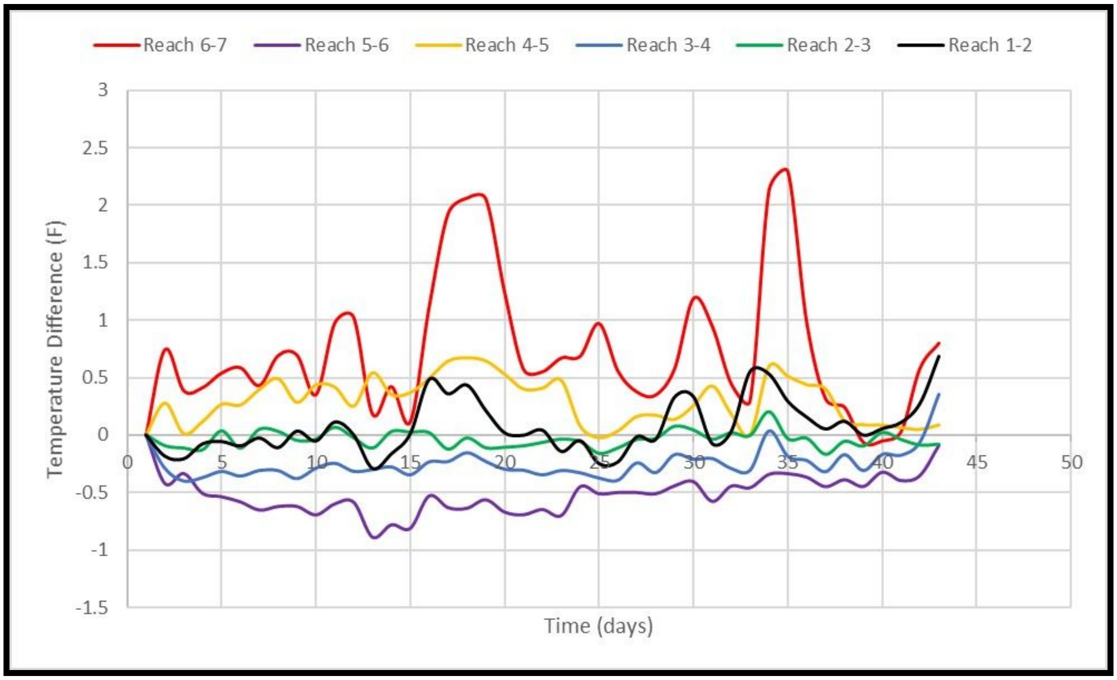


**Figure 5: ΔT between adjacent loggers.**
Logger 7 is closest to dam whereas logger 1 is near Bean's Bottom.

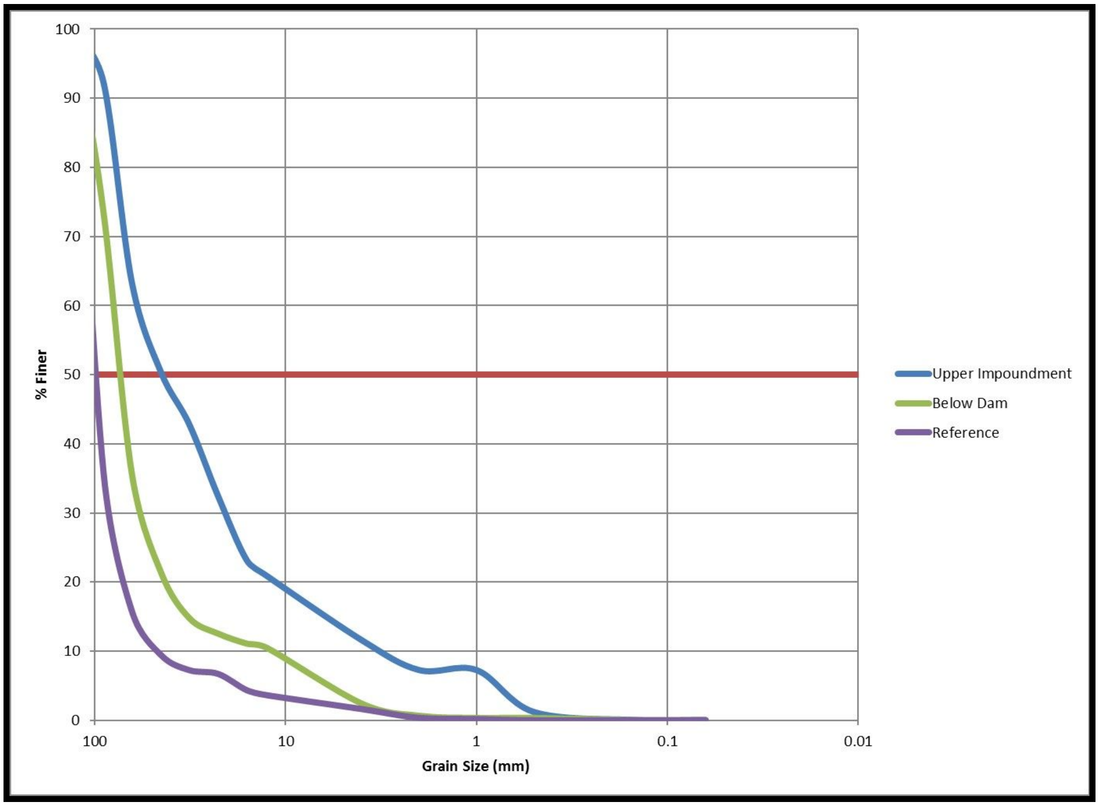


**Figure 6: Plot of grain size distribution.**
Y-axis indicates percent of bedload that is finer than the corresponding grain size.

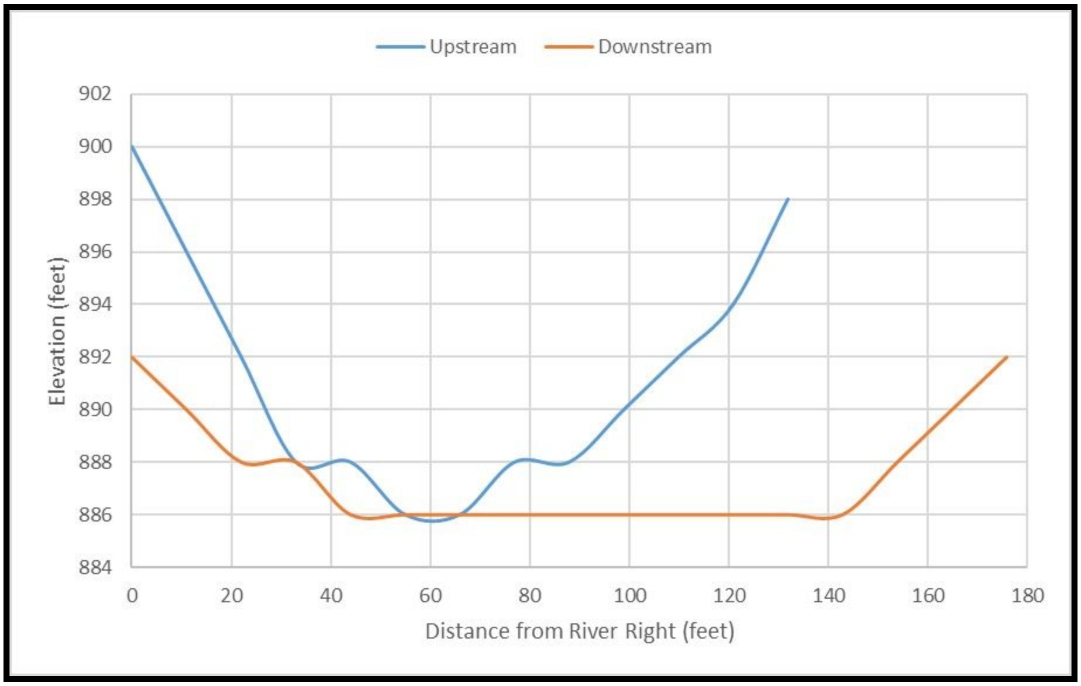


**Figure 7: Channel cross sections.**
Elevation is relative to sea level.

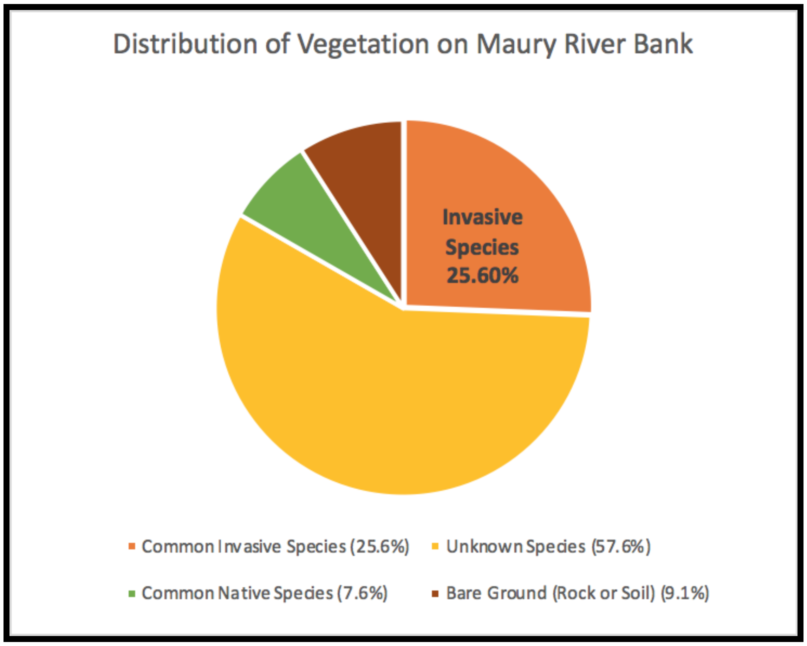


**Figure 8: Distribution of total Vegetation on Maury River banks (courtesy of Tucker and Fields 2017).**

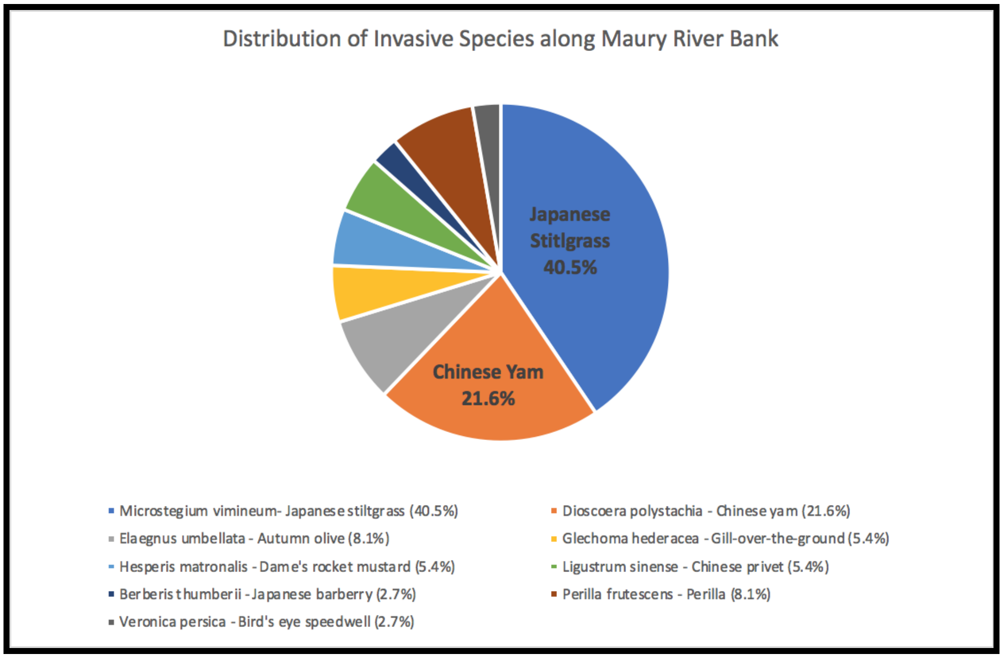


**Figure 9: Distribution of Invasive Species on Maury River banks (courtesy of Tucker and Fields 2017).**

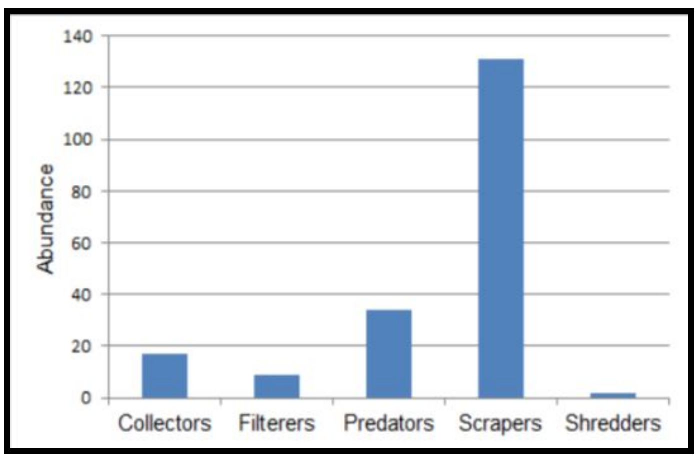


**Figure 10: Macroinvertebrate Functional Feeding Group Abundance (courtesy of Horan and Carmody 2017).**

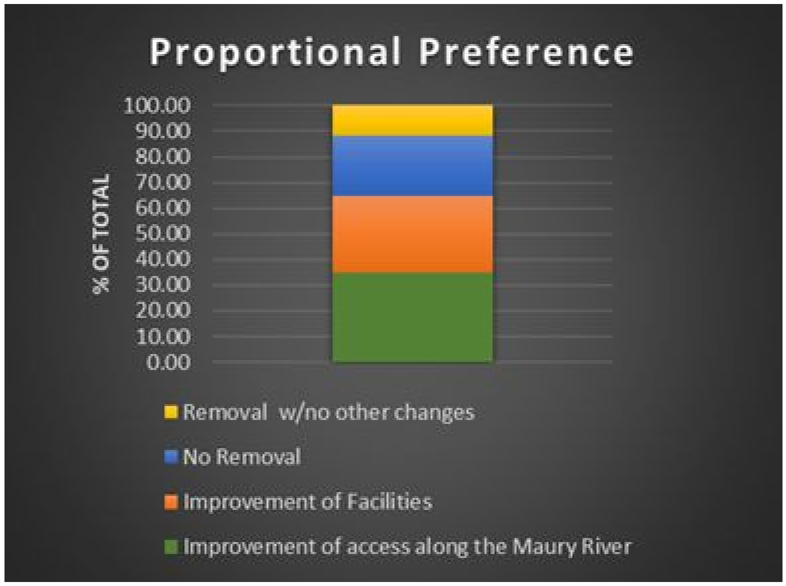


**Figure 11: Proportional preference of each scenario from resident preference survey.** Percentage shows total number of times the choice was chosen over other available options.

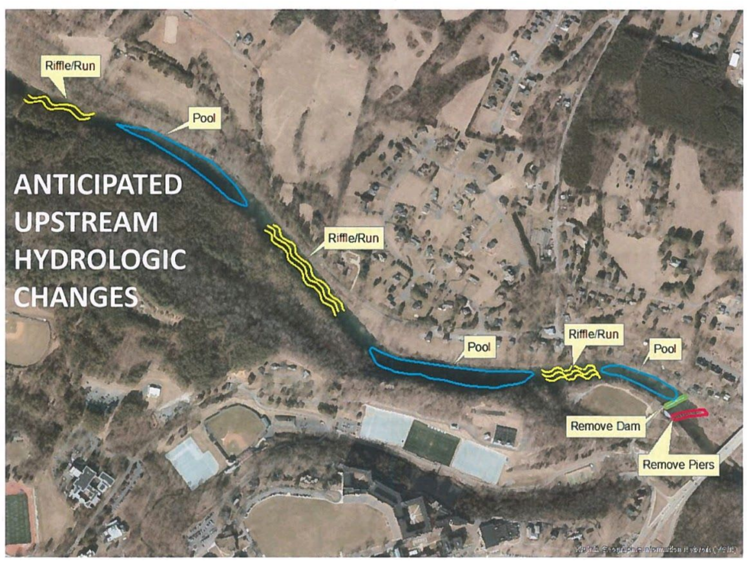


**Figure 12: Anticipated upstream hydrologic changes (courtesy of DGIF).**

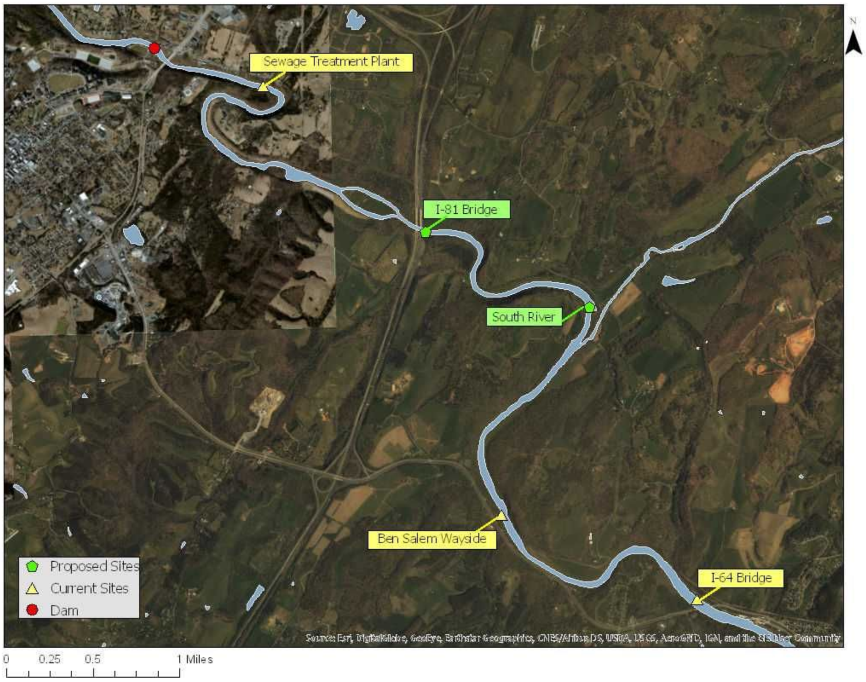


**Figure 13: Map of current and proposed Maury River access points.**

# Tables:

| Paired-Comparison Table | | | | |
|---|---|---|---|---|
| | No Removal | Improvement of Facilities | Improvement of access along the Maury River | Removal w/no other changes |
| No Removal | | | | |
| Improvement of Facilities | | | | |
| Improvement of access along the Maury River | | | | |
| Removal w/no other changes | | | | |

**Table 1: Pairwise comparison table for survey.**

| Scenarios | Total Upfront Cost | Total Annual Cost | % Preferred | Upfront Cost per Resident | Annual Cost per Resident |
|---|---|---|---|---|---|
| Removal and Improvement of Access | ~$86,000 | ~$7,000 | 34.7 | ~$2.90 | ~$0.23 |
| Removal and Improvement of Facilities | ~$44,000 | ~$3,200 | 29.9 | ~$1.50 | ~$0.10 |
| No Removal | ~$3,000,00 | ~$4,500 | 23.6 | ~$100 | ~$0.15 |
| Removal w/no other changes | ~$190,00 | 0 | 11.8 | N/A | N/A |
| *Removal of the dam is being funded by VDGIF thus Residents will not incur any added costs if no improvements are made.* | | | | | |

**Table 2: Total and per-resident costs of each scenario.**

| Basin | Jordan's Point | Buena Vista |
|---|---|---|
| Drainage Area (mi^2) | 494 | 647 |
| Mean Annual Discharge (cfs) | 515 | 674 |
| % area Valley and Ridge Province (carbonate) | 26.68 | 33.82 |
| % area Appalachian Plateua province (siliclastic) | 73.32 | 63.01 |
| % area Blue Ridge province (metamorphic) | 0 | 3.13 |
| % Barren | 0.04 | 0.04 |
| % cultivated crops | 17.61 | 19.7 |
| % developed/urban | 5.06 | 6.45 |
| % forested and shrub lands | 76.75 | 73.31 |
| % grassland | 0.17 | 0.15 |
| % surface water | 0.3 | 0.3 |
| Mean Annual Precipitation (in) | 44.98 | 45.25 |
| Average Soil Permeability (in/hr) | 3.775 | 3.663 |

**Table 3: Basin characteristics obtained from USGS StreamStats database.**

| | Above Dam | Below Dam | Reference |
|---|---|---|---|
| d50 (mm) | 51.14 | 69.06 | 89.31 |
| Size Classification | Coarse Gravel | Cobble | Cobble |

**Table 4: Grain size analysis results.**

| | Upstream | Downstream |
|---|---|---|
| Slope | 0.0012 | 0.0018 |
| Wetted Perimeter (ft) | 129.87 | 177.08 |
| Cross-Sectional Area (ft^2) | 985 | 836 |
| Hydraulic Radius (ft) | 7.58 | 4.72 |

**Table 5: Hydraulic geometry results.**

| Plant Type | Plant Name | Primary Colonizers | Soil Moisture Tolerance | Sunlight Tolerance | Growing Style/Speed | Seed Dispersal Method | Erosion Control | Population Control |
|---|---|---|---|---|---|---|---|---|
| Invasive | Chinese Yam | Yes | Yes *(prefers moist)* | Yes | Fast growing; dies in winter | Water | No | Herbicides *(not recommended by water)* |
| | Japanese Stiltgrass | Yes | Yes | Yes | Fast growing; dies in winter | Water *(1,000 seeds)* | No | Herbicides *(not recommended by water)* |
| Native | River Birch | Yes | No *(requires high soil moisture)* | No *(requires direct sunlight)* | Fast | Water | Yes *(deep roots stabilize sediment)* | Wildlife eat |
| | Sycamore | Yes | Somewhat *(can survive some flooding)* | No *(requires direct sunlight)* | Fast | Water | Yes | Wildlife eat |

**Table 6: Comparison of Invasive vs. Native Species for Vegetation of Maury River Banks.**

| | | | |
|---|---|---|---|
| **Richness** | 21 | **Richness Score** | 95.5 |
| **EPT[1] Taxa** | 13 | **EPT Score** | 118.2 |
| **%Ephemeroptera** | 18.7 | **%Ephem Score** | 30.5 |
| **%PT-Hydropsychidae[2]** | 16.6 | **%PT-H Score** | 46.6 |
| **%Scrapers** | 67.9 | **%Scraper Score** | 131.6 |
| **%Chironomidae** | 0.0 | **%Chironomidae Score** | 100 |
| **%2Dominant Taxa[3]** | 46.6 | **%2Dom Score** | 77.2 |
| **Modified Family Biotic Index[4]** | 4.1 | **%MFBI Score** | 86.8 |
| - | - | **Stream Condition Index** | 85.8 |

Score equations found in Table 6.1 of Burton and Gerritsen (2003). [1]*ephemeroptera+plecoptera+trichoptera;* [2]*P+T, not including hydropsychidae family;* [3]*sum of abundances of 2 most abundant families;* [4]*sum of (tolerance*abundance) value for each family, divided by total abundance*

**Table 7: Macroinvertebrate Survey Results (courtesy of Horan and Carmody 2017).**

| | SMB # | Between 9/28 and 10/19 (river m) | Between 10/19 and 10/26 (river m) | Total Distance (river m) | Displacement (river m) |
|---|---|---|---|---|---|
| Upstream | 1 | -24 | 0 | 24 | -24 |
| | 2 | -180 | -71 | 251 | -251 |
| | 3 | | | 0 | 0 |
| | 4 | -302 | 1648 | 1950 | 1347 |
| | 5 | 1403 | 140 | 1543 | 1543 |
| | 6 | -460 | 96 | 557 | -364 |
| Downstream | 7 | -963 | -684 | 1646 | -1646 |
| | 8 | 0 | 0 | 0 | 0 |
| | 9 | -184 | -1403 | 1587 | -1587 |
| | 10 | -297 | -1419 | 1716 | -1716 |
| | 11 | 93 | -109 | 202 | -17 |
| | 12 | -303 | 303 | 606 | 0 |
| | 13 | | 235 | 235 | 235 |
| | 14 | -1585 | 0 | 1585 | -1585 |
| | 15 | 48 | -1433 | 1481 | -1385 |
| | | | **Upstream Release** | **865** | **450** |
| | | | **Downstream Release** | **1103** | **-992** |
| | | | **Average** | **1011** | **-437** |

**Table 8: Smallmouth Bass Displacement (courtesy of Ross and Wang 2017).**

| Effect | Positive | Neutral | Negative |
|---|---|---|---|
| **Fish** | Largemouth Bass (*Micropterus salmoides*), Rock Bass (*Ambloplites rupestris*), Smallmouth Bass *(Micropterus dolomieu*), Bluegills (*Lepomis macrochirus*), River Chub (*Nocomis micropogon),* Longnose Dace *(Rhinichthys cataractae),* Fantail Darter *(Etheostoma flabellare),* Longfin Darter *(Etheostoma longimanum),* Black Jumprock *(Moxostoma cervinum),* Margined Madtom *(Noturus insignis),* Bluntnose Minnow *(Pimephales notatus),* Pumpkinseed *(Lepomis gibbosus),* Common Shiner *(Luxilus cornutus),* Rosyface Shiner *(Notropis rubellus)*, Swallowtail Shiner *(Notropis procne),* Central Stoneroller *(Campostoma anomalum),* Northern hog Sucker *(Hypentelium nigricans),* Torrent Sucker *(Thoburnia rhothoeca),* White Sucker *(Catostomus commersoni),* Mottled Sculpin *(Cottus bairdii)* | Bluehead chub (*Nocomis leptocephalus)*, Bull Chub *(Nocomis raneyi),* Fallfish *(Semotilus corporalis),* Redhorse Golden *(Moxostoma erythrurum),* Rosefin Shiner *(Lythrurus ardens),* Satinfin Shiner *(Cyprinella analostana),* Green Sunfish *(Lepomis cyanellus),* Redbreast Sunfish *(Lepomis auritus)* | Brown Bullhead (*Ameiurus nebulosus),* Yellow Bullhead (*Ameiurus natalis),* Common Carp *(Cyprinus carpio), T*essellated Darter *(Etheostoma olmstedi)* |

**Table 9: Long-term effects of Jordan's Point Dam Removal on Maury River Fish.**

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## Acknowledgements:

We would like to thank Dr. Jim Kahn, Dr. Robert Humston, Mrs. Emily Falls, and Mrs. Louise Finger for their aid on this project.

# Appendix:

**Appendix 1: Survey Attribute Descriptions**

***No Removal***

After its inspection by two separate companies it was deemed that that the Jordan's Point Dam had serious flaws in its structural integrity. If the dam is not removed, the city will need to repair it beginning in 2018 due to its failure to meet safety requirements specified by the Dam Safety and Floodplain Management Division of the Virginia Department of Conservation and Recreation. The costs incurred in the repairs deemed necessary by the two inspections would be between 2.5 and 3 million dollars. These costs would allow the following repairs "grouting all voids, encasing the downstream face of the dam in concrete, installing anchors through the dam into the riverbed below, and pouring a new reinforced concrete cap" (Lexington City Council Meeting 1/4/2018) so that the dam may be brought up to standards. With the approximate number of residents in Rockbridge County totaling around thirty thousand citizens, the taxes incurred by residents would be ~\$100 for the upfront cost of restructuring the dam and ~\$0.15 annually for maintenance, per resident, if the City were intent on keeping the dam rather than opting to remove it.

***Removal and Improvement of Facilities***

The improvement of current facilities can take on many forms around the current access points along the Maury River. These improvements could include the addition of small shelters, walking trails, picnic areas, and even concrete boat ramps for easier access. While the costs of these improvements are relative to the area and scale to which they will be constructed, there are national averages for the costs of constructing and maintaining these structures that will be used as estimates for proposed improvements. The preference for improvement of current facilities in this case will include a small picnic area, a small shelter that includes trash cans and grills, a small walking trail that is approximately 3' wide by 1,000' in length and made of a loose material, and a reinforced-concrete boat ramp. The total upfront costs of these endeavors would be estimated at ~\$44,000 with annual maintenance costs estimated at ~\$3,200. With the approximate number of residents in Rockbridge County totaling around 30,000, this would be a one-year tax of ~\$1.50 for the upfront cost and ~\$0.10 annually for maintenance of these facilities. Two locations that could use all of these amenities are the Sewage Treatment Plant take-out off of Old Buena Vista Rd and the I-64 bridge take-out off of Stuartsburg Rd in Buena Vista. The Jordan's Point Park and Ben-Salem Wayside take-outs could use some of these facilities, such as a concrete boat ramp, but already have picnic tables, grills, trash cans, etc.

***Removal and Improvement of River Access***

Access improvement applies to locations where the river may be accessible but there is no infrastructure such as roads, paths, boat ramps, picnic areas, trash cans, etc. These costs will therefore include not only those amenities listed in the facilities improvement section above, but also an access road, 15 spot parking lot, and a half an acre of open ground on which the above structures would be built. In addition to the ~$44,000 upfront cost and the ~$3,200 yearly costs calculated above, an additional ~$42,000 would be added to the total cost and ~ $3,800 would be added to the annual costs. This would bring the total upfront cost to ~$86,000 and the annual costs up to ~$7,000. Considering the Rockbridge County populace totals at around 30,000 residents, this would be an upfront cost of about $2.90 per resident and an annual cost of about $0.23 per resident for the initial construction of a complex with not only parking spaces, an access road and an open area to construct the above structures but also a picnic area, small shelter, walking trail, and boat ramp. Two such locations at which this manner of improvement would take place are at the junction of the South and Maury Rivers and the space along the Chessie Trail where the I-81 bridge crosses the Maury River.

***Removal w/no other Changes***

Currently the only plan of action the City of Lexington has taken is to approve the VDGIF's plans to remove the dam beginning on October 1st, 2018. Under the agreement between the city and the VDGIF, there will be no costs to the city concerning the removal of the dam as it is the VDGIF's responsibility to acquire funding to complete the project, estimated at about $190,00 in total. If the city decides not to improve any facilities or create any new access points the dam will be removed and there will be no further costs to the city or the citizens of Rockbridge county that spur from the removal of the dam.

**Appendix Table 2: Common Local Species at Maury River, Jordan's Point (courtesy of Tucker and Fields 2017)**

| Common Local Species | | | | |
|---|---|---|---|---|
| **Scientific Name** | **Common Name** | | **Scientific Name** | **Common Name** |
| *Alliara petiolata* | Garlic mustard (invasive) | | *Perilla frutescens* | Perilla (invasive) |
| *Ailanthus altissima* | Tree of heaven (invasive) | | *Rosa multiflora* | Multiflora rose (invasive) |
| *Berberis thunbergii* | Japanese barberry (invasive) | | *Rubus phoenicolasius* | Wineberry (invasive) |
| *Corydalis incisa* | Incised fumewort (invasive) | | *Stellaria media* | Common chickweed (invasive) |
| *Dioscorea polystachya* | Chinese yam (invasive) | | *Veronica persica* | Bird's-eye speedwell (invasive) |
| *Elaeagnus umbellata* | Autumn Olive (invasive) | | *Asimina triloba* | Pawpaw (native) |
| *Glechoma hederacea* | Gill-over-the-ground (invasive) | | *Acer negundo* | Boxelder maple (native) |
| *Hesperis matronalis* | Dame's rocket mustard (invasive) | | *Lindera benzoin* | Spicebush (native) |
| *Lamium purpureum* | Purple dead-nettle (invasive) | | *Physocarpus opulifolia* | Ninebark (native) |
| *Ligustrum sinense* | Chinese privet (invasive) | | *Platanus occidentalis* | Sycamore (native) |
| *Lonicera japonica* | Japanese honeysuckle (invasive) | | *Verbesina alternifolia* | Wingstem (native) |
| *Microstegium vimineum* | Japanese Stiltgrass (invasive) | | | |

**Appendix Table 3: Abundance and Tolerance of Macroinvertebrate Survey (courtesy of Horan and Carmody 2017).**

| Family ID | Common Name | Order | FFG[1] | Tol.[2] | Abun.[3] |
|---|---|---|---|---|---|
| Leptophlebiidae | Prong-gilled mayfly | Ephemeroptera | Collector | 2 | 2 |
| Leptoceridae | Longhorned caddisfly | Trichoptera | Collector | 4 | 1 |
| Philopotamidae | Fingernet caddisfly | Trichoptera | Collector | 3 | 10 |
| Oligochaeta | Earthworm | Oligochaeta | Collector | 8 | 2 |
| Psychomyiidae | Net-tube caddisfly | Trichoptera | Collector | 2 | 2 |
| Hydropsychidae | Netspinning caddisfly | Trichoptera | Filterer | 4 | 5 |
| Isonychiidae | Brushlegged mayfly | Ephemeroptera | Filterer | 2 | 1 |
| Brachycentridae | Humpless casemaker caddisfly | Trichoptera | Filterer | 1 | 1 |
| Sphaeriidae | Fingernail clam | Pelecypoda | Filterer | 8 | 2 |
| Perlidae | Common stonefly | Plecoptera | Predator | 1 | 11 |
| Coenagrionidae | Narrowwinged damselfly | Odonata-Zygoptera | Predator | 9 | 15 |
| Hydracarina | Aquatic mite | Hydracarina | Predator | 5 | 1 |
| Perlodidae | Perlodid stonefly | Plecoptera | Predator | 2 | 3 |
| Gomphidae | Clubtail dragonfly | Odonata-Anisoptera | Predator | 1 | 3 |
| Rhyacophilidae | Free-living caddisfly | Trichoptera | Predator | 0 | 1 |
| Pleuroceridae | Gilled snail | Gastropoda | Scraper | 6 | 7 |
| Elmidae | Riffle beetle | Coleoptera | Scraper | 4 | 55 |
| Psephenidae | Water penny | Coleoptera | Scraper | 4 | 35 |
| Heptageniidae | Flatheaded mayfly | Ephemeroptera | Scraper | 4 | 33 |
| Glossosomatidae | Saddle-case caddisfly | Trichoptera | Scraper | 0 | 1 |
| Pteronarcyidae | Giant stonefly | Plecoptera | Shredder | 0 | 2 |

Total abundance = 193. Tolerance values taken from Mandaville (2002).
[1]*FFG = functional feeding group;* [2]*Tol. = tolerance value;* [3]*Abun. = abundance*