Stream Habitat Conditions in the North River Before and After Restoration Activities; North River Ranger District, George Washington Jefferson National Forest, Virginia 2019

United States Department of Agriculture Forest Service
Southern Research Station
Center for Aquatic Technology Transfer
1710 Research Center Drive
Blacksburg, VA 24060-6349

C. Andrew Dolloff, Project Leader

Report prepared by:
Colin Krause[1], Craig Roghair[1], and Dawn Kirk[2]
February 2021

[1]USDA Forest Service
Southern Research Station
Center for Aquatic Technology Transfer
1710 Research Center Dr.
Blacksburg, VA 24060

[2]USDA Forest Service
George Washington and Jefferson
National Forests
27 Ranger Lane
Natural Bridge Station, VA 24579

Table of Contents

List of Figures

List of Tables

Introduction

Land use practices such as logging, clearing for agriculture, road building, and stream channelization have resulted in long-term impairment in streams throughout the southeastern United States. Stream bank and channel erosion, channel down-cutting, and the loss of structural habitat elements, particularly large wood, have greatly simplified streams and decreased habitat suitability for a variety of fish species, including Brook Trout (*Salvelinus fontinalis*), the only salmonid native to the Eastern US. Efforts to restore habitat complexity include construction of instream enhancement structures typically comprised of natural materials such as large wood and boulders. Structures increase pool volume, depth, and frequency, promote flushing of fine sediment, sorting and deposition of spawning gravels, and enhance refuge habitat, particularly during periods of low flow (House and Boehne 1985, Nagayama and Nakamura 2010, Riley and Fausch 1995, Roni et al. 2008, Seehorn 1992). Numerous studies have demonstrated that these manipulations of stream habitat increase the abundance, biomass, and spawning of salmonids and other fishes (House and Boehne 1985, Nagayama and Nakamura 2010, Riley and Fausch 1995, Roni et al. 2008, White et al. 2011).

Artificial structures composed of large wood are not permanent, and like natural structures they will eventually decompose and decrease in effectiveness, but they can contribute to habitat complexity and fish (trout) abundance for well over 20 years (White et al. 2011). Structures comprised of rock, such as large boulders, are often used instead of or in addition to large wood structures to create long-term habitat complexity. While most studies have found that instream structures result in a positive response (e.g. increased abundance and enhanced spawning) by salmonids, the results are less definitive for non-salmonids and macroinvertebrates (Nagayama and Nakamura 2010, Roni et al. 2008). To maximize the benefits of restoration, structures must be designed for the type of stream and habitat requirements of fish and other aquatic species (Nagayama and Nakamura 2010). Furthermore, factors such as instream flow, water quality, riparian shade, erosion potential, etc., must also be addressed (Roni et al. 2008). Finally, even though the benefits of large wood and rock structures may last decades, the ultimate goal of restoration is to restore the natural processes that sustain seasonal flow patterns, maintain habitat complexity, and provide for natural recruitment of large wood (Nagayama and Nakamura 2010).

The North River, located in the Appalachian Mountains of Virginia, flows east from an elevation of 1,100 m through the George Washington-Jefferson National Forest (GWJNF), past Bridgewater, VA, and into the South Fork Shenandoah River. On June 17th, 1949 a steady rain fell throughout the day and night resulting in a catastrophic flood, which claimed 3 lives, damaged over 100 homes, and washed out roads and bridges (CSPDC 2013, HRHS 2008). Following this flood, large portions of the North River above Elkhorn Lake were channelized in an effort to protect the reconstructed roadway and bridges. Between 1959 and 1965, 69 gabion walls, 7 cross-channel weirs, and 17 in-channel wing deflectors (groins) were installed within a 9.3 km reach of river. Although intended to stabilize and control the river, these structures caused excessive down-cutting in some areas, and deposition of cobble-sized materials in others. In November of 1985, Hurricane Juan removed or buried many of these structures, resulting in further disruption of pool/riffle topology and loss of habitat complexity. Consequently, large sections of the stream dewater during periods of low flow, particularly during the summer.

The goals of stream habitat improvement projects in the North River include restoration of the stream channel morphology and enhanced channel resilience to extreme events to provide a fishery for native Brook Trout. A series of cross-vane and J-hook in-stream structures made of rock and wood have been installed to create and maintain low-water pools that will serve as essential habitat during droughts and seasonal low-flow periods. Additionally, deteriorating gabions were removed to allow the river to access its floodplain and a bankfull bench was established.

We inventoried sections of the North River within the North River Ranger District, GWJNF, Virginia, in 2002 and 2005, prior to stream habitat restoration, in 2014 following initial rounds of restoration projects, and in 2019 after the completion of all restoration projects to quantify stream habitat conditions. Here, we compare stream habitat before and after habitat restoration to assess the effectiveness of the restoration efforts to date.

Inventory Sections

Our inventory reach contained two contiguous sections, originally described during a 2005 basin-wide inventory of the North River (Ivasauskas et al. 2006). Section D was approximately 5.6 km long and extended from the northwest corner of Elkhorn Lake, upstream to the Forest Road 95 bridge; Section E was approximately 5.1 km long and extended from the Forest Road 95 bridge, upstream to the confluence with the Little River (Figure 1, Table 1). The sections had similar width, gradient, and depths, but Section D had more pool area and was less constrained within its valley bottom, providing for wider floodplains. USGS flow gage #01620500 is located near the downstream end of Section D (Figure 1), which allowed us to monitor discharge during our inventories.

We first inventoried what would later be labeled as Section D during a 2002 habitat inventory project (Fitzpatrick et. al 2003). We inventoried Section D a second time, and Section E for the first time in 2005. The GWJNF completed the first set of restoration projects near the upstream end of Section E after our summer 2005 inventory. Restoration in Section E was extended downstream through several additional project phases from 2006 to 2013 (Figure 1, Table 2). We inventoried Section D and Section E again in 2014 (Krause et al. 2015). In 2014 there were no additional structures added to the channel, but two cross-vanes were repaired. Two final rounds of restoration work were completed in Section E in

2015 - 2016, and a small restoration area was added to Section D in 2017. We returned for post-restoration inventories of Reach D and Reach E in 2019.

Methods

We used the basinwide visual estimation technique (BVET) (Dolloff et. al 1993), which is a two-stage method to inventory stream habitat. During the first stage, habitat was stratified into similar groups based on naturally occurring habitat units including pools (areas in the stream with concave bottom profile, gradient equal to zero, greater than average depth, and smooth water surface), and riffles (areas in the stream with convex bottom profile, greater than average gradient, less than average depth, and turbulent water surface). Glides (areas in the stream similar to pools, but with average depth and flat bottom profile) were identified during the inventory but were grouped with pools for data analysis. Runs (areas in the stream similar to riffles but with average depth, less turbulent flow, and flat bottom profile) and cascades (areas in the stream with > 12% gradient, high velocity, and exposed bedrock or boulders) were grouped with riffles for data analysis.

Habitat in each section of stream was classified and inventoried by a 2 or 3-person crew. One crew member identified each habitat unit by type (as described above), estimated average wetted width, average and maximum depth, riffle crest depth, substrate composition, and percent fines. The length of each habitat unit was measured with a hip chain. Average wetted width was visually estimated. Average and maximum depth of each habitat unit were estimated by taking depth measurements at various places across the channel profile with a graduated staff marked in 5 cm increments. The riffle crest depth was estimated by measuring water depth at the deepest point in the hydraulic control between riffles and pools. The riffle crest depth was subtracted from average pool depth to obtain an estimate of residual pool depth. Substrates were assigned to one of nine size classes (Appendix A). Dominant substrate (covering the greatest amount of surface area in the habitat unit) and subdominant substrate (covering the second greatest amount of surface area in the habitat unit) were visually estimated. Also visually estimated were percent fines, which is the percent surface area of the streambed consisting of sand, silt, or clay substrate particles (particles < 2 mm diameter). In addition, several attributes of road-stream crossings (location, type, size, etc.) were recorded, where encountered.

The second crew member classified and inventoried large wood within the bankfull channel and recorded all data. Large wood was assigned to one of four size classes (Appendix A). All wood less than 1.0 m long and less than 10 cm in diameter were omitted from the inventory. The third crew member, when present, assisted with measurements.

For stream reaches that were dry or did not contain enough water to form distinguishable habitat units, the only data collected was the length of the dry section. The 2014 and 2019 inventories are an exception where the quantity of large wood within the bankfull channel of dry sections was also recorded. In this report we limit our large wood analysis to wetted sections, which had large wood data collected in all inventory years.

The first habitat unit of each habitat type selected for intensive (second stage) sampling (e.g. accurate measurement of wetted width) was determined randomly. Additional units were selected systematically (every 10th habitat unit type for streams >1000 m and every 5th habitat unit type for streams <500 m). The wetted width of each systematically selected habitat unit was measured with a meter tape across at least three transects and averaged. In each of the systematically selected (second stage) riffles we also measured the bankfull channel width, left and right channel's riparian width, channel gradient, and water temperature, as well as took a photograph. Bankfull channel width was determined by measuring the width of the bankfull channel perpendicular to flow. Riparian width was measured from the edge of the bankfull channel to the intersection with the nearest landform at an elevation equal to two-times the maximum bankfull depth as described by Rosgen (1996). Gradient was estimated by using a clinometer to sight from the downstream to the upstream end of the selected riffle. These measurements enabled the Rosgen channel type to be calculated (Rosgen 1996 and Appendix A). Water temperature was measured with a thermometer in flowing water, out of direct sunlight.

All estimates, measurements, and confidence intervals from the stream habitat inventories were summarized using Microsoft Excel and formulas found in Dolloff et al. (1993). See Appendix A for detailed field methods.

Results

Flow

The North River experienced frequent flashy flows during the periods in-between our inventories (Figure 2). We performed inventories in summer when flows were at or near their annual low. The daily mean discharge was 1.2 cfs to 2.0 cfs on the days we conducted habitat inventories (Figure 3, Table 3). Flow increased by 0.3 cfs to 0.7 cfs on the second inventory day in 2002, 2005 and 2014; in 2014 it was noted that there were afternoon thunderstorms on day 1 and this is likely the cause in 2002 and 2005 as well (Figure 3, Table 3).

Section D

Our analysis of stream habitat in Section D is focused on habitat changes over time without consideration of habitat restoration project impacts. The only restoration actions taken in Section D during our monitoring project were the addition of 4 structures around a bridge in 2017 (Figure 1, Table 2). The effect of these additions is not detectable at the scale of our analysis.

The wetted areas of Section D contained an average of 41% pool area across all years, with a maximum of 53% in 2019 and a minimum of 29% in 2005 (Figure 4, Table 4). Riffle area increased from 2002 – 2005, then decreased each year thereafter (Figure 5, Table 4). On average, 17% of the length of Section D was dry, with a low of 8% in 2005 to a high of 23% in 2014. Dry areas generally increased as flow decreased (Figures 2, 3, and 6, Tables 3 and 4).

The quantity of large wood per kilometer fluctuated greatly among years, with a noticeable peak in 2014 (Figure 7). Most of the variation among years was accounted for by large fluctuations in small (10-55 cm) diameter pieces (Figure 7, Table 5). We tallied a maximum of 2 pieces of the largest size class (pieces greater than 5 m long, greater than 55 cm diameter) in any given year. Large wood was scattered throughout the section, but generally was higher from rkm 0 – 1 and rkm 3 – 5 than in the rest of the section (Figure 8).

Substrate in riffles and pools was dominated by large gravel and cobble, with scattered boulder and occasional bedrock substrates as well (Table 6, Figures 9-12). Fines (sand, silt, and clay) were consistently low throughout the length of Section D (Figure 13, Table 7).

We observed pools of varying depths and sizes throughout Section D. The mean of average, maximum, and residual pool depths in Section D ranged from 28 cm to 35 cm, 47 cm to 61 cm, and 19 cm to 26 cm, respectively (Table 7). Section D was interspersed with deep (80-130 cm) pools, but maximum depths were typically less than 60 cm (Figure 14). The average of wetted pool widths was similar across sample years (range: 4.3-4.4 m) (Table 7). We encountered pools least frequently in 2005 and most frequently in 2014 (Figure 15, Table 4).

Section E

We completed a pre-restoration inventory of Section E in 2005, a mid-restoration inventory in 2014, and a post-restoration inventory in 2019 (Table 1). Between fall 2005 and fall 2013, 65 habitat improvement structures were added to Section E; another 31 structures were added from 2015 – 2016 (Table 2).

The wetted area of Section E consisting of pools increased from 13% in 2005 to 24% in 2014 and 2019 (Figure 4, Table 4). Total pool area increased significantly from 2005 to 2014, then decreased in 2019, whereas total riffle area decreased each year (Figure 5, Table 4). The total length of dry stream channel increased from 1% in 2005, to 14% in 2014, and 33% in 2019 (Figure 6, Table 4), corresponding to decreased discharge (Figures 2 and 3, Table 3). We observed dry pools downstream of some restoration structures during our 2019 inventory (Appendix B).

The quantity of large wood per kilometer fluctuated greatly among years, with a noticeable peak in 2014 (Figure 7). Most of the variation among years was accounted for by large fluctuations in small

(10-55 cm) diameter pieces (Figure 7, Table 5). We tallied a maximum of 3 pieces of the largest size class (pieces greater than 5 m long, greater than 55 cm diameter) in any given year. Large wood was scattered throughout the section, with no discernable pattern across years (Figure 16).

Substrate in riffles and pools was dominated by large gravel, cobble, and boulder with occasional bedrock substrates as well (Table 6, Figures 17-19). Fines (sand, silt, and clay) were consistently low throughout the length of Section D (Figure 20, Table 7).

The mean of average pool depths declined from 33 cm in 2005, to 32 cm in 2014, and to 25 cm in 2019) (Table 7). The mean of maximum pool depths decreased each sample year, with a high of 62 cm in 2005 to a low of 41 cm in 2019 (Table 7). The mean of residual pool depths increased from 19 cm to 25 cm from 2005 to 2014, then declined to 20 cm in 2019 (Table 7). Section E was interspersed with deep (60-100 cm) pools, but maximum depths were typically less than 60 cm (Figure 21). The average of pool widths was highest at 4.8 m in 2005 and lowest at 3.6 m in 2019 (Table 7). These declines in pool depth and width correspond to decreased discharge (Figures 2 and 3, Table 3). Pools were distributed throughout Section E and reaches with restoration structures had a noticeable increase in pool frequency in 2014 and 2019 (Figure 22, Table 4).

Discussion

Differences in stream habitat among our various inventories could be attributed to both stream discharge and restoration activities. The difference in discharge among years was small in absolute terms, with the highest discharge around 2 cfs and lowest discharge around 1 cfs, but this represented a 50% reduction in flow. The sections responded differently to changes in discharge. Section D fluctuated from 8% - 23% dry channel with little correlation between discharge and percent dry channel. Discharge and percent dry channel were correlated in Section E, with 1% dry channel in the wettest year and 33% dry channel in the driest year. Both sections lost significant amounts of riffle habitat as their channels dried, which resulted in a corresponding increase in pool to riffle ratio. We also found a paradoxical increase in total pool area in both sections during the driest years. We suspect that as flow decreased and riffles dried, some formerly riffle habitats presented as glides or shallow pools.

The effect of stream restoration projects on habitat in Section E was difficult to tease apart from the effect of change in flow. We observed a noticeable increase in the quantity of pools and a decrease in riffle length (i.e. distance between pools) in 2014 and 2019 in Section E. We also found a significant increase in pool area and proportion of pool habitat in 2014, following the initial round of habitat restoration projects. However, we did not see an increase in 2019, following a second round of projects. The number of structures installed in 2015 – 2016 was about half the number installed previously and coupled with lower flow may have resulted in no significant gains in pool area or proportion during our

2019 inventory. In fact, flow was so low in Section E that ‘pools’ downstream of several restoration structures were dry in 2019 (see photos in Appendix B).

The North River experiences frequent flashy flows and has a highly mobile bed, as indicated by the unembedded large gravel and cobble substrates we encountered throughout the inventory reaches. Large wood is also clearly being flushed through the system, as indicated by a significant loss of wood between our 2014 and 2019 inventories. Long-term monitoring will be needed to determine both the longevity of the structures and efficacy of forest management at recruiting large wood of sufficient size to form log jams and maintain their position in the channel over time. Natural wood recruitment increases habitat complexity, pool formation, and the channel’s ability to maintain summer surface flow. The big increase in large wood during the 2014 inventory was likely from eastern hemlock trees killed by the hemlock wooly adelgid. When the hemlocks are gone, future large wood recruitment will depend on other tree species filling that gap in the stream’s riparian area. As stream habitat complexity increases, the likelihood that large wood will remain within Section D and E rather than being flushed out during high flow events also increases, leading to development of a self-sustaining system.

The goal of the instream enhancement structures is to help the North River move towards a dynamic equilibrium that will maintain summer surface flow and ultimately enhance aquatic biota, specifically the Brook Trout fishery. Sampling fish was beyond the scope of our work here, but the Virginia Department of Wildlife Resources (DWR) has been monitoring fish populations in the North River for several years, which will provide valuable insight into restoration effectiveness. An increase in pool habitat should be beneficial to Brook Trout populations (Nagayama and Nakamura 2010, Roni et al. 2008), particularly during summer or any period of low flow.

Our results also highlight the perilous link between flow and habitat quality and quantity in the North River. The GWJNF has received requests for water withdrawals across the Forest. We observed increased channel drying as flows decreased, and in the driest years even pools were dewatered in some sections. Supplemental water withdrawals would be detrimental to maintaining ecological flow and runs counter to the objectives of stream restoration in the North River.

The North River upstream of Elkhorn Lake has a long history of channel modifications and ultimate success of the latest round of restoration activities is yet to be determined. Given the dynamic nature of the channel, we strongly recommend additional habitat and fish monitoring. Additional habitat monitoring following the methods established here, in combination with continued fish sampling by DWR, will provide powerful evidence as to the effectiveness of stream and riparian restoration activities.

Data Availability

North River stream habitat data reside in a MS Access database, which is managed by the CATT, and a copy has been provided to Dawn Kirk, GWJNF Forest Fish Biologist. We will work with the GWJNF to develop custom queries and reports for the MS Access database, as needed.

Literature Cited

Central Shenandoah Planning District Commission (CSPDC). 2013. Central Shenandoah Valley all hazards mitigation plan. Staunton, VA: CSPDC. 342 pp.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. General Technical Report SE-83. Asheville, North Carolina: U.S. Department of Agriculture, Southeastern Forest Experiment Station.

Everest, F. H., R. L. Beschta, J. C. Scrivener, K V. Koski, J. R. Sedell, and C. J. Cederholm. 1987. Fine sediment and salmonid production: a paradox. pages 98-142 in E. O. Salo and T. W. Cundy, eds. Streamside Management: Forestry and Fishery Interactions, Contrib. # 57, University of Washington, Seattle.

Fitzpatrick, E., D. Nuckols, C. Holbrook, A. Skelton, C. Roghair and C. Dolloff. 2003. Condition of streams in the South Fork Shenandoah River Drainage, 2002-2003, Dry River Ranger District, George Washington-Jefferson National Forest, VA. Unpublished File Report. Blacksburg, VA: U.S. Department of Agriculture, Southern Research Station, Center for Aquatic Technology Transfer. 153 pp.

Harrisonburg-Rockingham Historical Society (HRHS). 2008. The flood of 1949 in Bridgewater. The Harrisonburg-Rockingham Historical Society Newsletter. 30:1-5.

House, R.A. and P.L. Boehne. 1985. Evaluation of instream enhancement structures for Salmonid spawning and rearing in a coastal Oregon stream. North American Journal of Fisheries Management. 5:283-295.

Ivasauskas, T., C. Kyger, C. Roghair and C. Dolloff. 2006. Stream habitat conditions in the North River, Dry River Ranger District, George Washington-Jefferson National Forest, VA, 2005.Unpublished File Report. Blacksburg, VA: U.S. Department of Agriculture, Southern Research Station, Center for Aquatic Technology Transfer. 44 pp.

Krause, C., C. Roghair, C.A. Dolloff, and D. Kirk. 2015. Summary of Stream Habitat Inventories in the North River; North River Ranger District, George Washington Jefferson National Forest, Virginia 2014. Unpublished File Report. Blacksburg, VA: USDA Forest Service, Southern Research Station, Center for Aquatic Technology Transfer. 63 pp.

Nagayama, S. and F. Nakamura. 2010. Fish habitat rehabilitation using wood in the world. Landscape and Ecological Engineering. 6:289-305.

Riley, S.C. and K.D. Fausch. 1995. Trout population response to habitat enhancement in 6 northern Colorado streams. Canadian Journal of Fisheries and Aquatic Sciences. 52:34-53

Roni, P., K. Hanson, and T. Beechie. 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management. 28:856-890.

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology Books, Pagosa Springs, Colorado.

Seehorn, M. E. 1992. Stream habitat improvement handbook, Technical Publication R8-TP 16, USDA Forest Service, Southern Region, 1720 Peachtree Road, N. W., Atlanta, GA.

White, S.L., G.C. Gowan, K.D. Fausch, J.G. Harris, and W.C. Saunders. 2011. Response of trout populations in five Colorado streams two decades after habitat manipulation. Canadian Journal of Fisheries and Aquatic Sciences. 68:2057-2063.

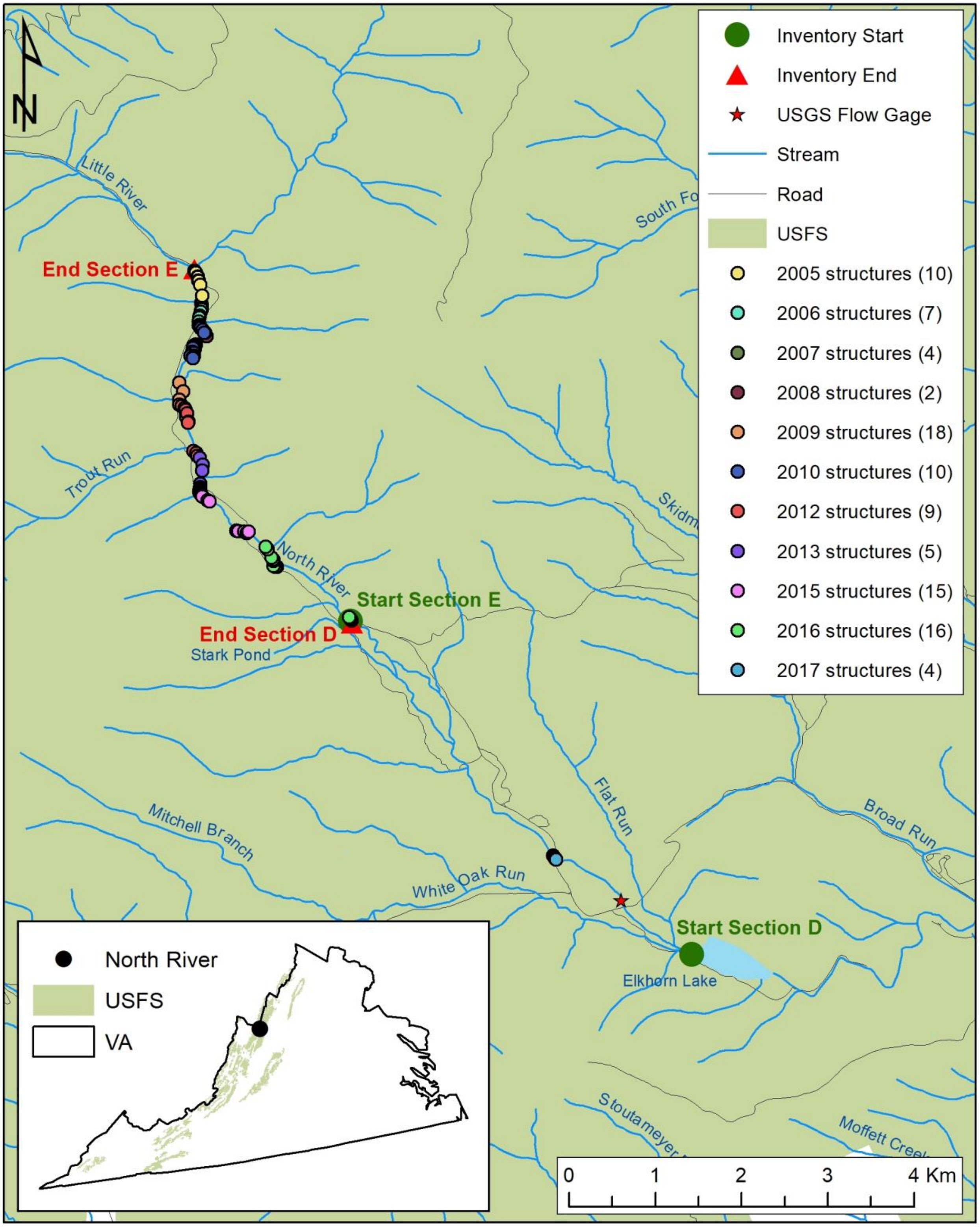


Figure 1. Location of BVET inventoried reaches (Sections D and E) and restoration structures (quantity and year installed) on the North River; North River Ranger District, George Washington National Forest, Virginia.

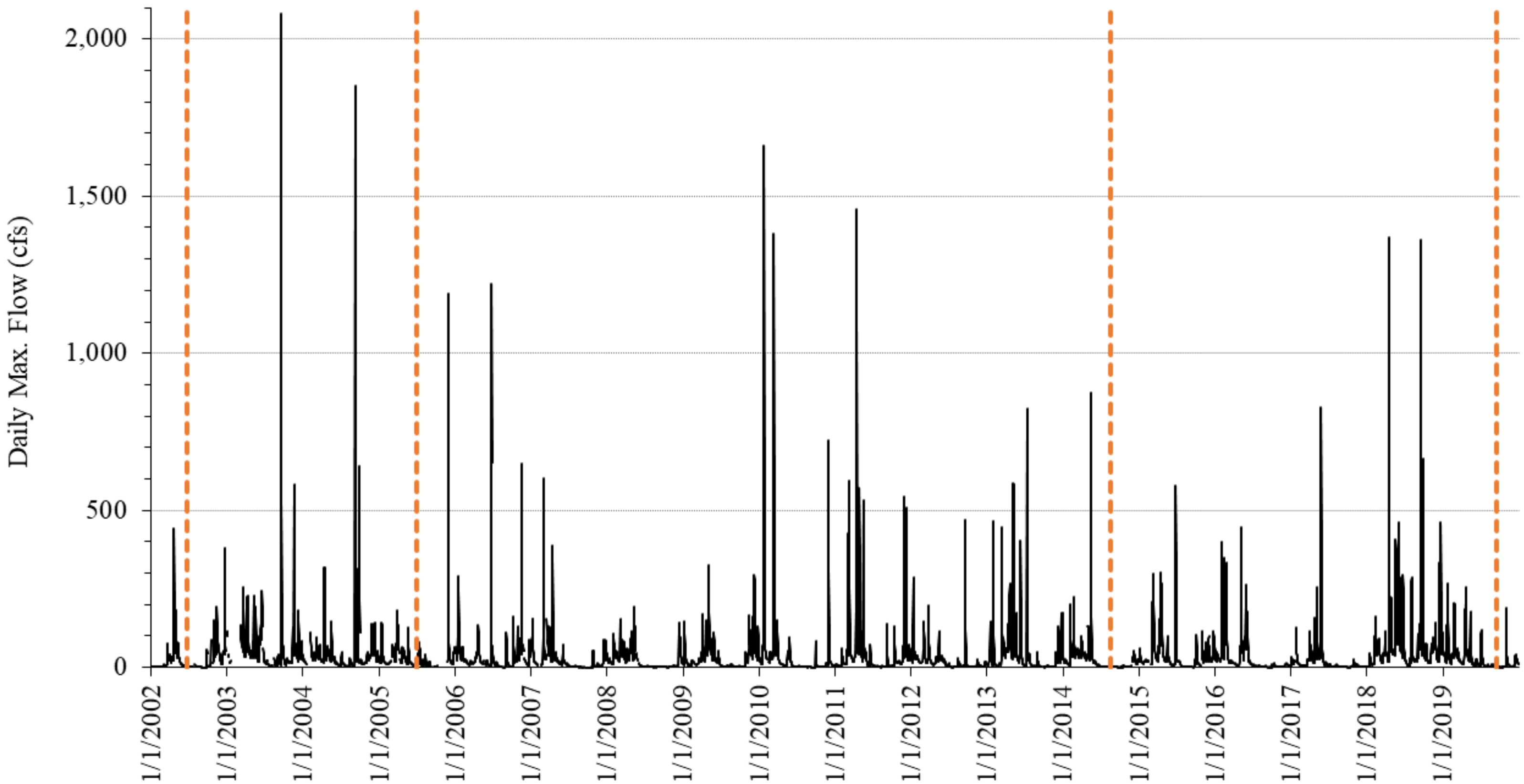


Figure 2. Daily maximum flow (cfs) from 2002-2019; dashed orange lines indicate BVET inventory dates.

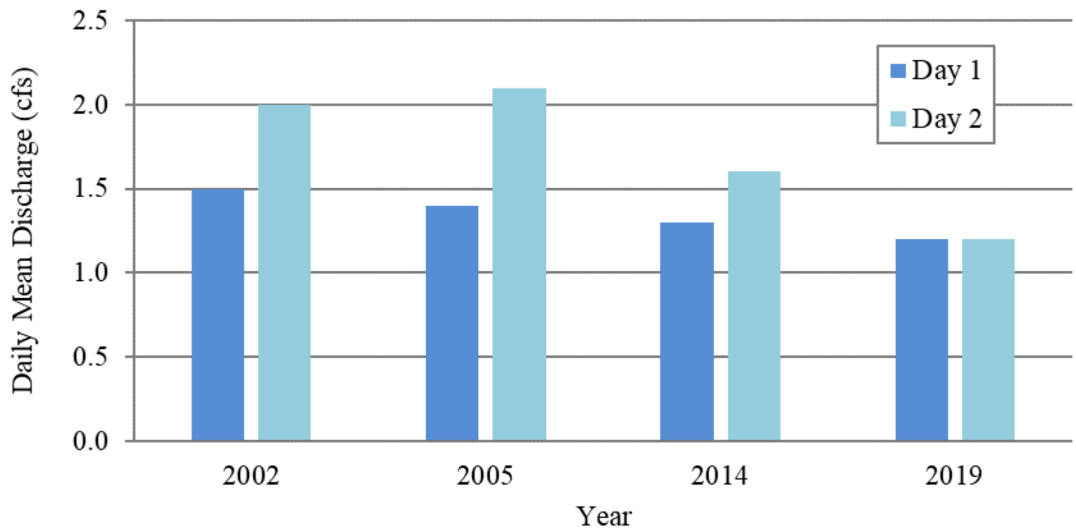


Figure 3. Daily mean discharge at USGS flow gage #01620500 (North River near Stokesville, VA) on days 1 and 2 for each year's BVET inventory.

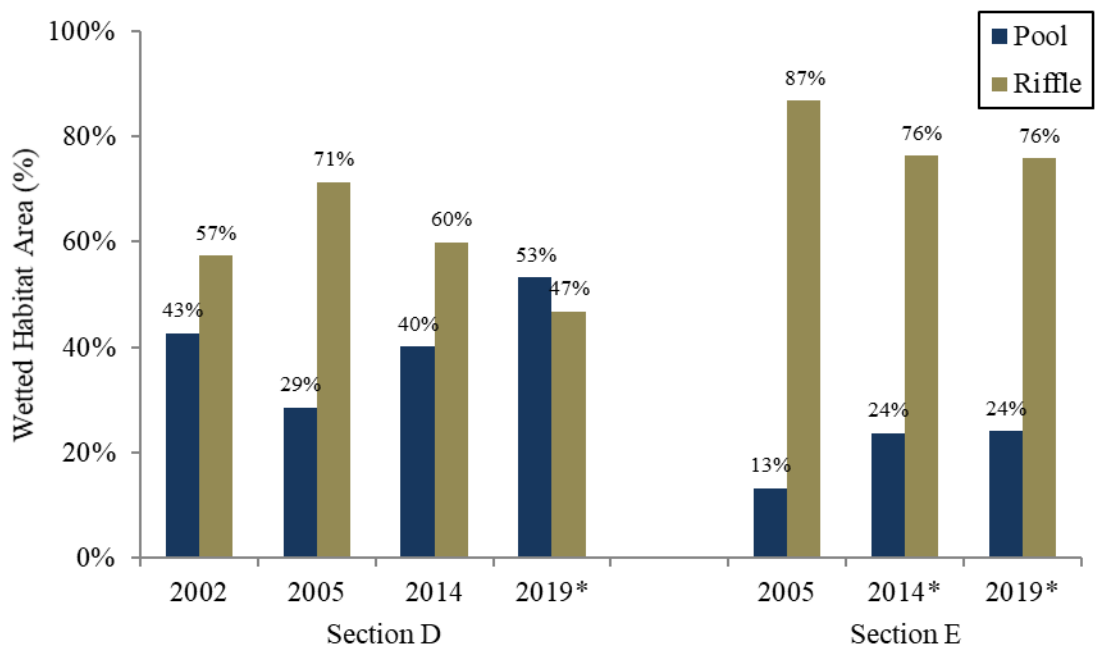


Figure 4. Percent pool and riffle wetted habitat area. **restoration structures present*

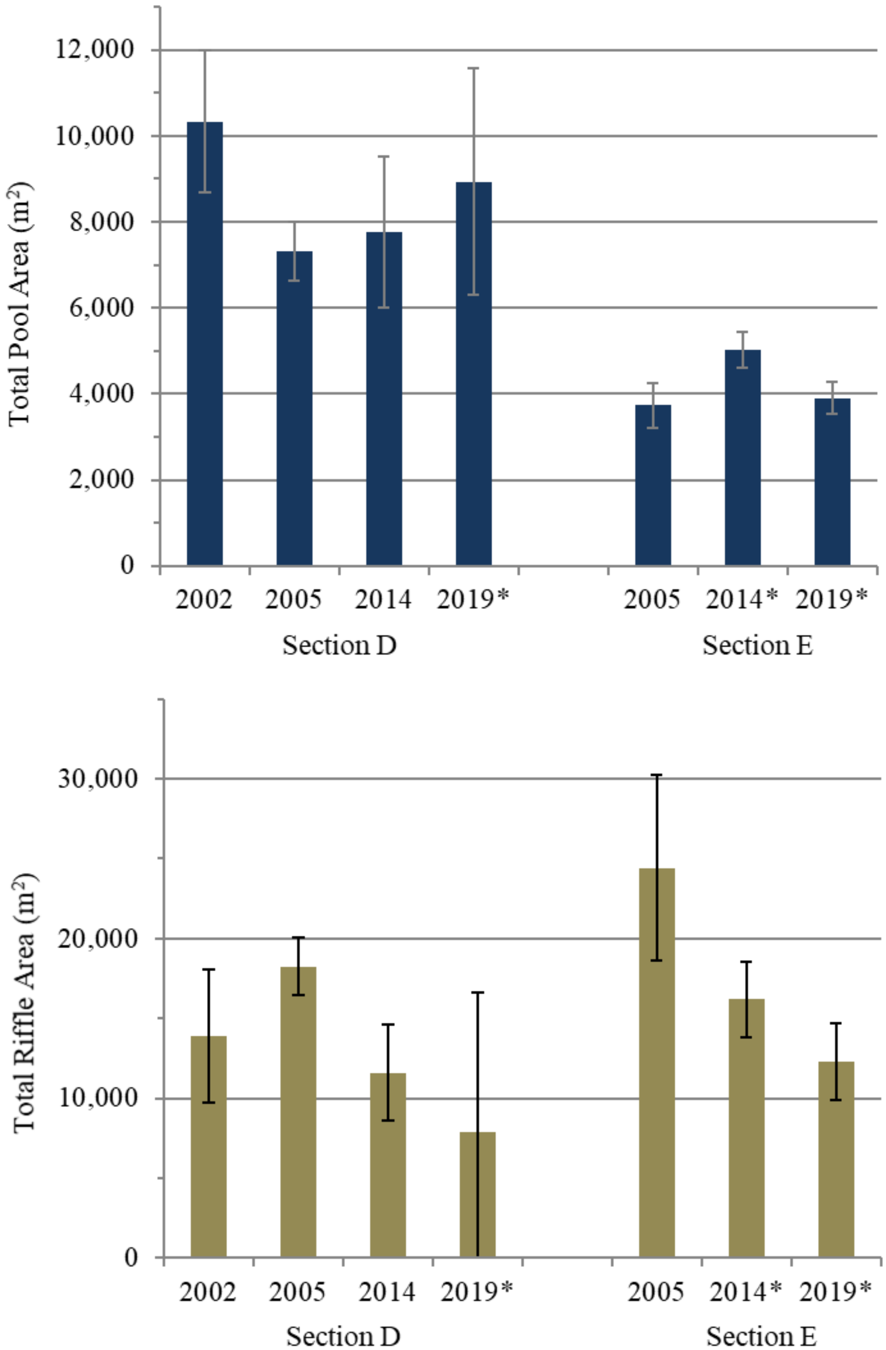


Figure 5. Total pool and riffle habitat area (m^2). **restoration structures present*

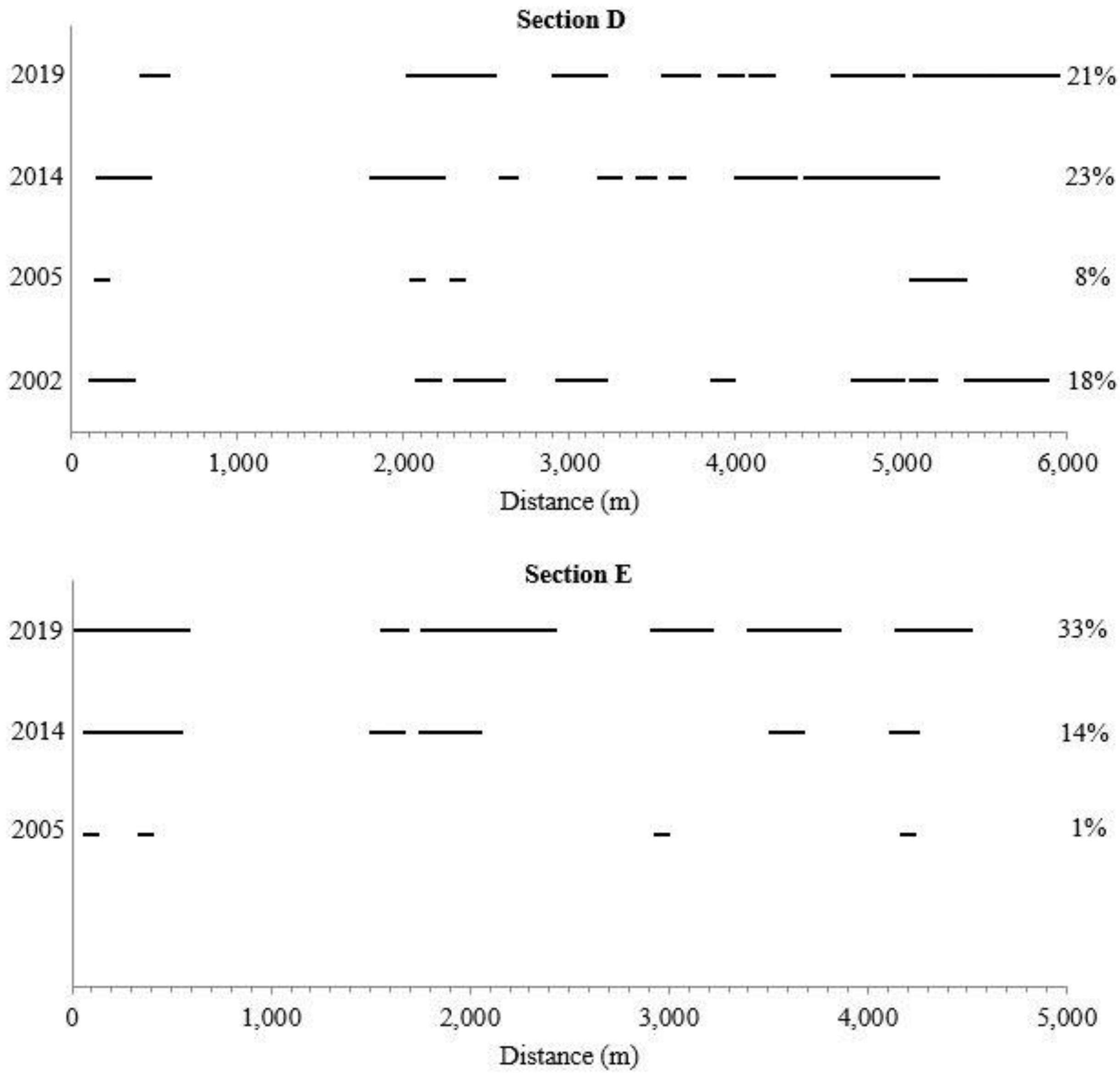


Figure 6. Dry reaches in Sections D and E during the 2002, 2005, 2014, and 2019 inventories; total percent dry channel area shown to right. Note that due to variability in inventoried BVET habitat distances between years, dry sections may be offset from one another by ~600 m in Section D and ~300 m in Section E when comparing between years.

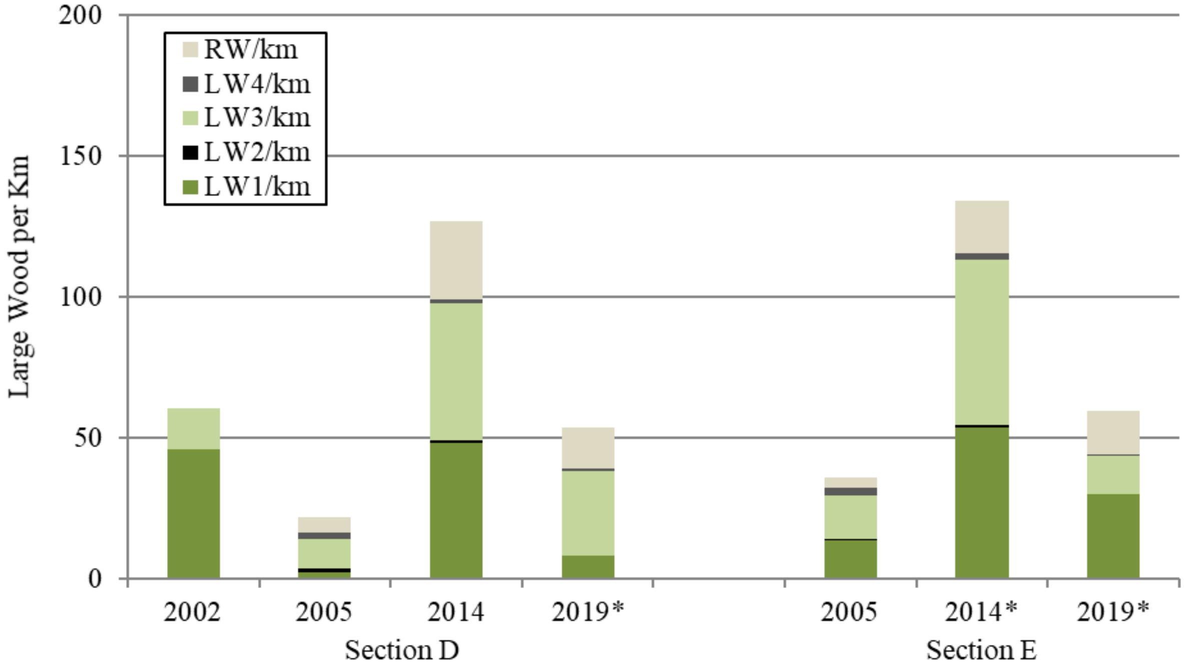


Figure 7. Quantity of large wood (LW; dead and down, any part within bankfull channel) per kilometer in Sections D and E. LW size classes: LW1 = 1-5 m length, 10-55 cm diameter; LW2 = 1-5 m length, >55 cm diameter; LW3 = >5 m length, 10-55 cm diameter; LW4 = >5 m length, >55 cm diameter; RW = rootwad (counts within dry sections in 2014 and 2019 are excluded for comparison with prior years). **restoration structures present*

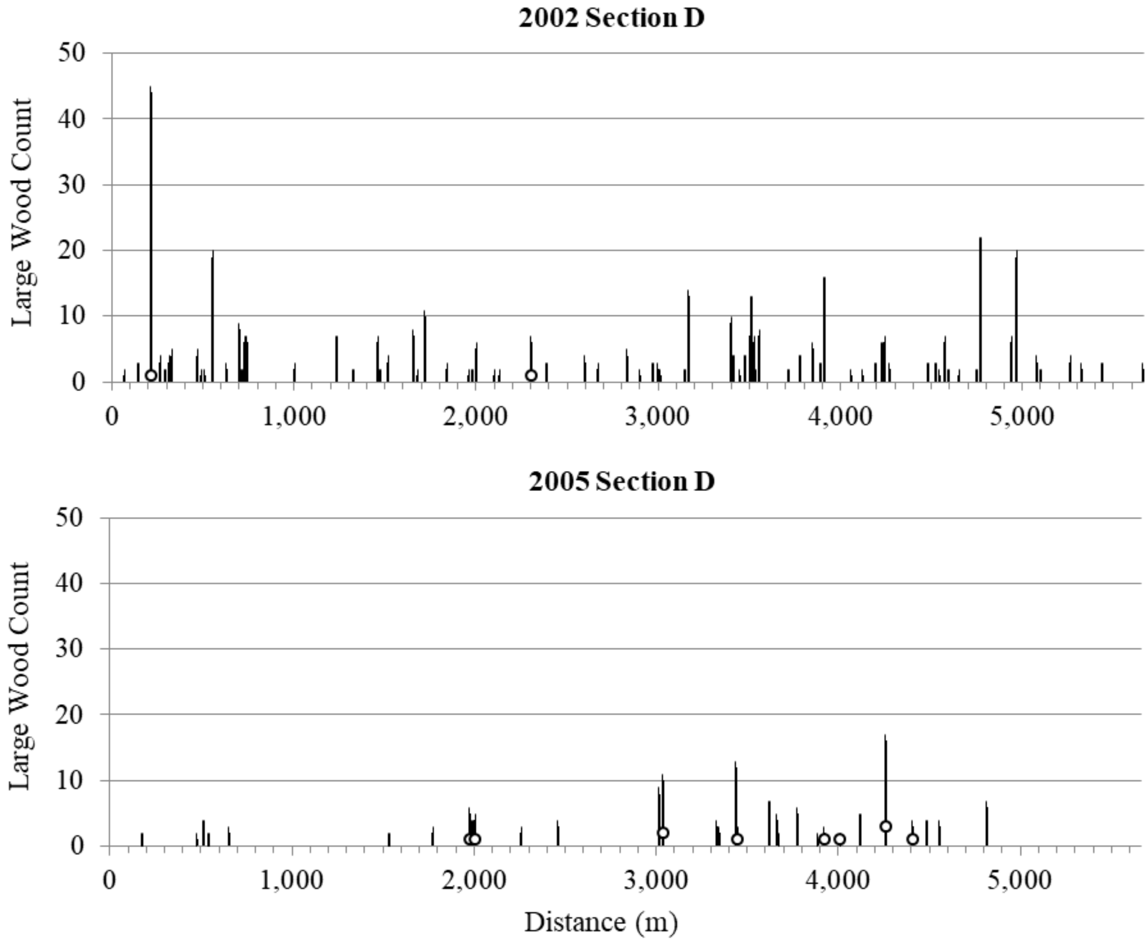


Figure 8. Count of large wood (bars = size classes 1, 2, 3, 4, and rootwad combined; open circles = size 4 only) within Section D in 2002, 2005, 2014, and 2019 (figure continued on next page). Counts of large wood occurred within pools and riffles (counts within dry sections in 2014 and 2019 are excluded for comparison with prior years).

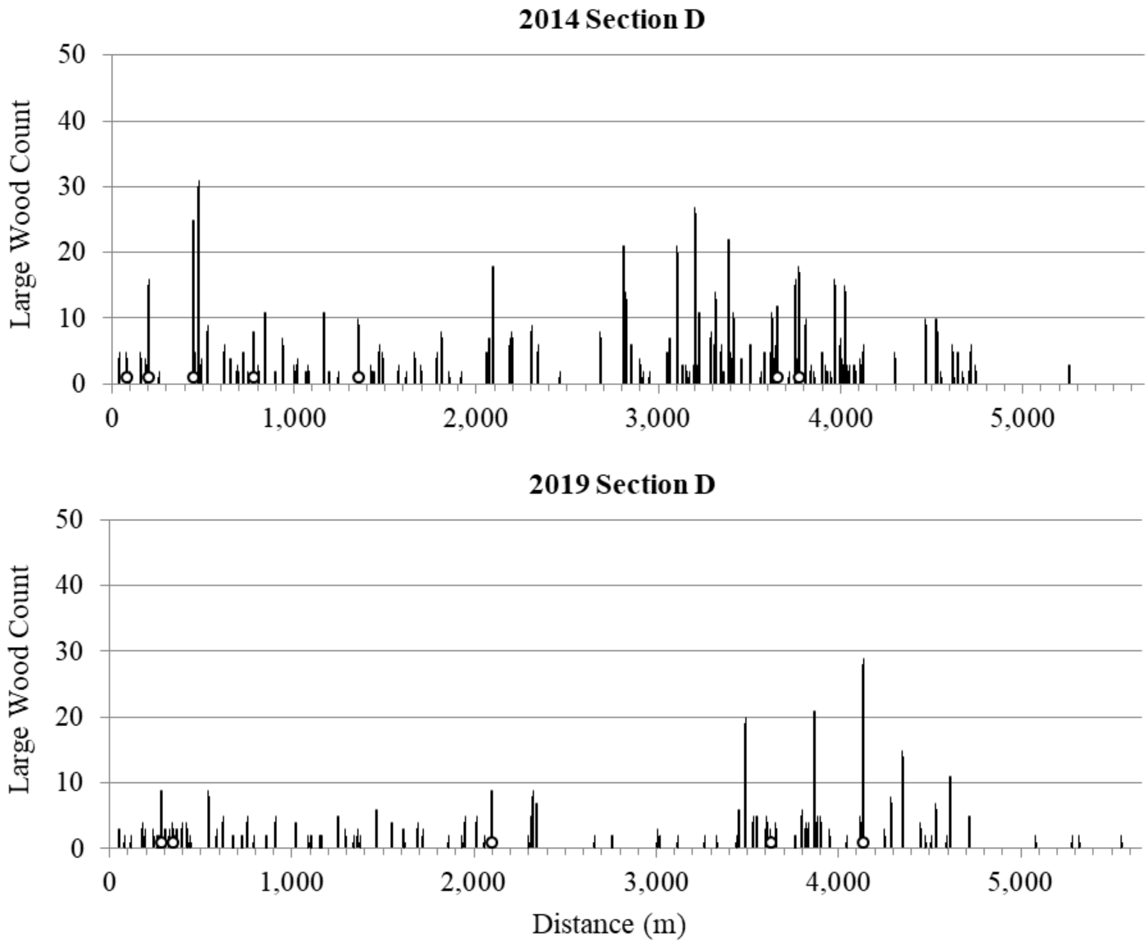


Figure 8 continued. Count of large wood (bars = size classes 1, 2, 3, 4, and rootwad combined; open circles = size 4 only) within Section D in 2002, 2005, 2014, and 2019. Counts of large wood occurred within pools and riffles (counts within dry sections in 2014 and 2019 are excluded for comparison with prior years).

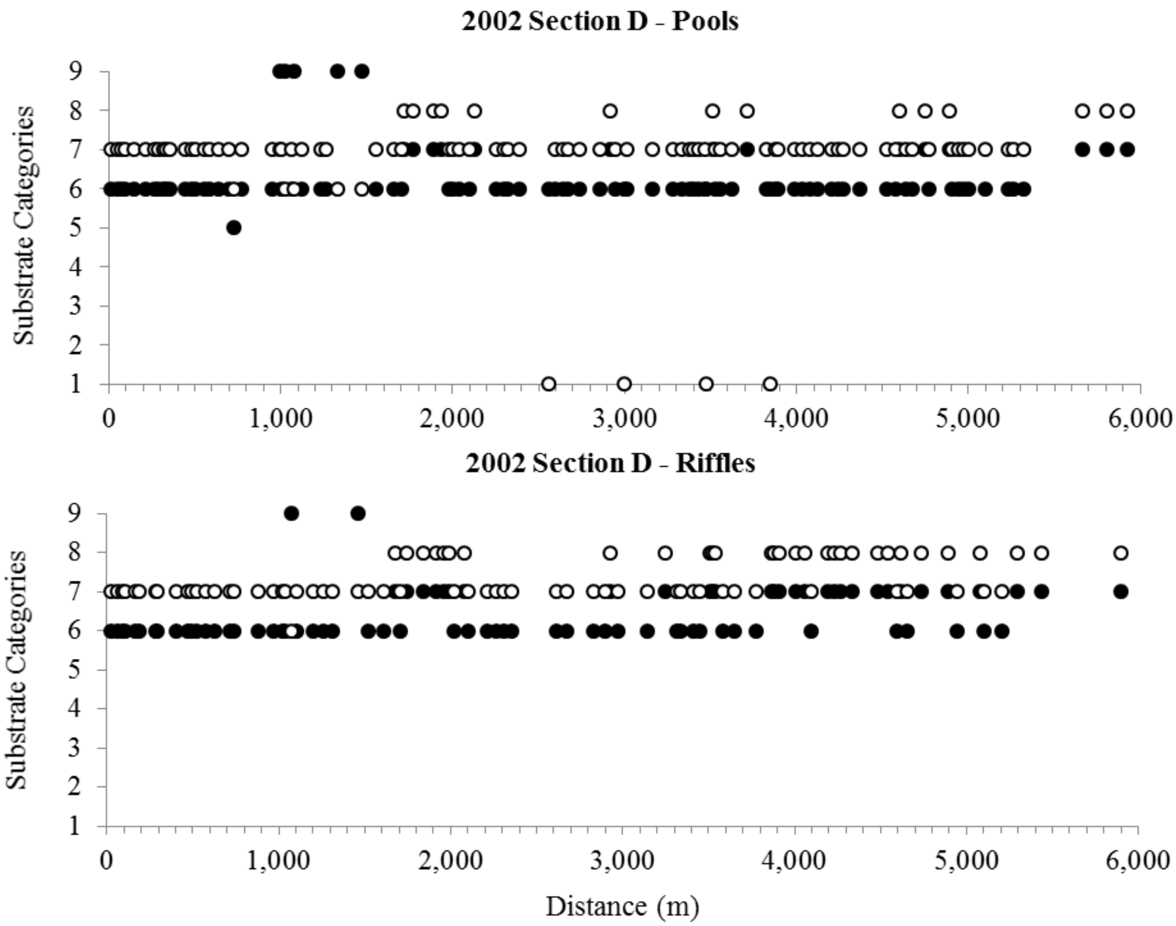


Figure 9. Dominant (solid circles) and subdominant (open circles) substrate category present in each pool (upper graph) and riffle (lower graph) within Section D in 2002. Substrate size categories: 1 Organic Matter = dead leaves, detritus, etc.; 2 Clay = sticky, holds form; 3 Silt = slippery, doesn't hold form; 4 Sand = silt-2 mm; 5 Small Gravel = 3-16 mm; 6 Large Gravel = 17-64 mm; 7 Cobble = 65-256 mm; 8 Boulder = >256 mm; 9 Bedrock = solid rock.

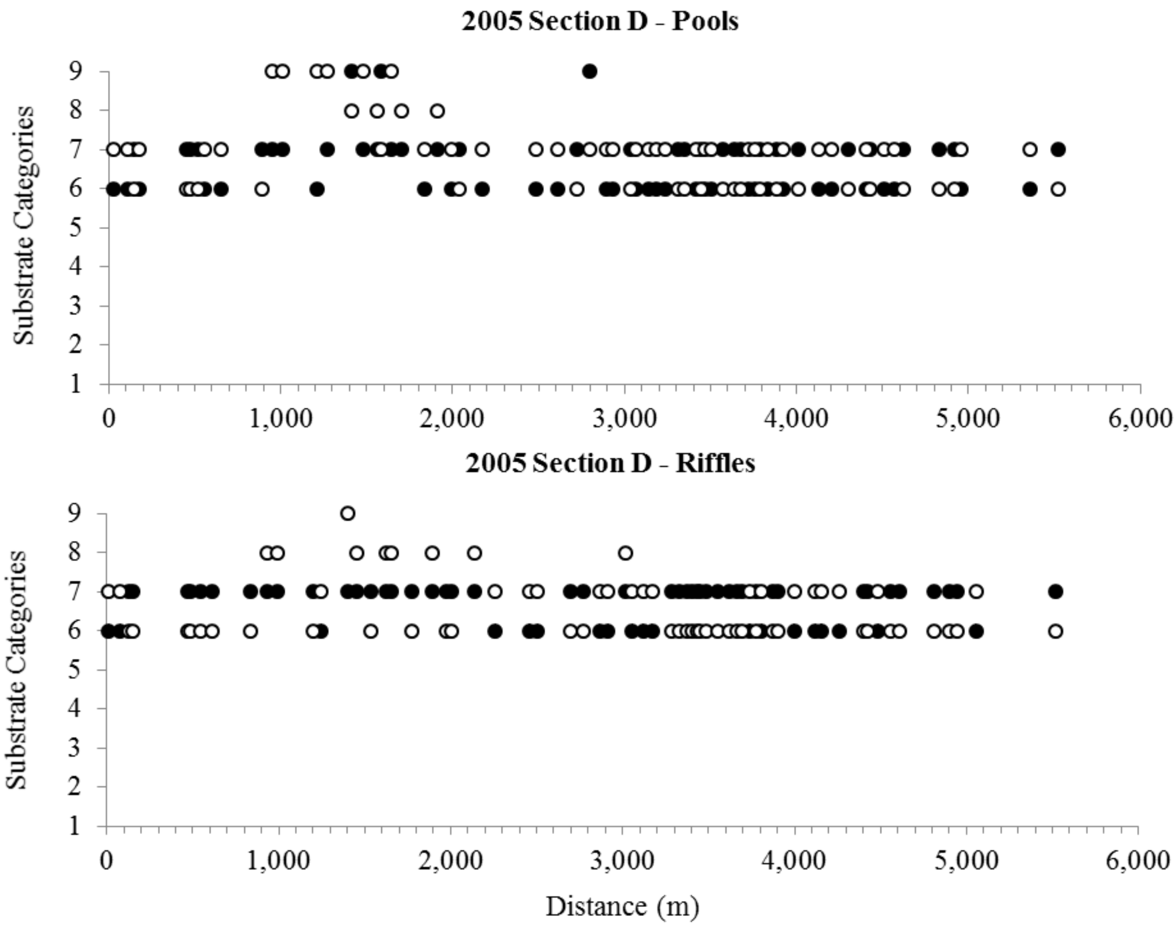


Figure 10. Dominant (solid circles) and subdominant (open circles) substrate category present in each pool (upper graph) and riffle (lower graph) within Section D in 2005. Substrate size categories: 1 Organic Matter = dead leaves, detritus, etc.; 2 Clay = sticky, holds form; 3 Silt = slippery, doesn't hold form; 4 Sand = silt-2 mm; 5 Small Gravel = 3-16 mm; 6 Large Gravel = 17-64 mm; 7 Cobble = 65-256 mm; 8 Boulder = >256 mm; 9 Bedrock = solid rock.

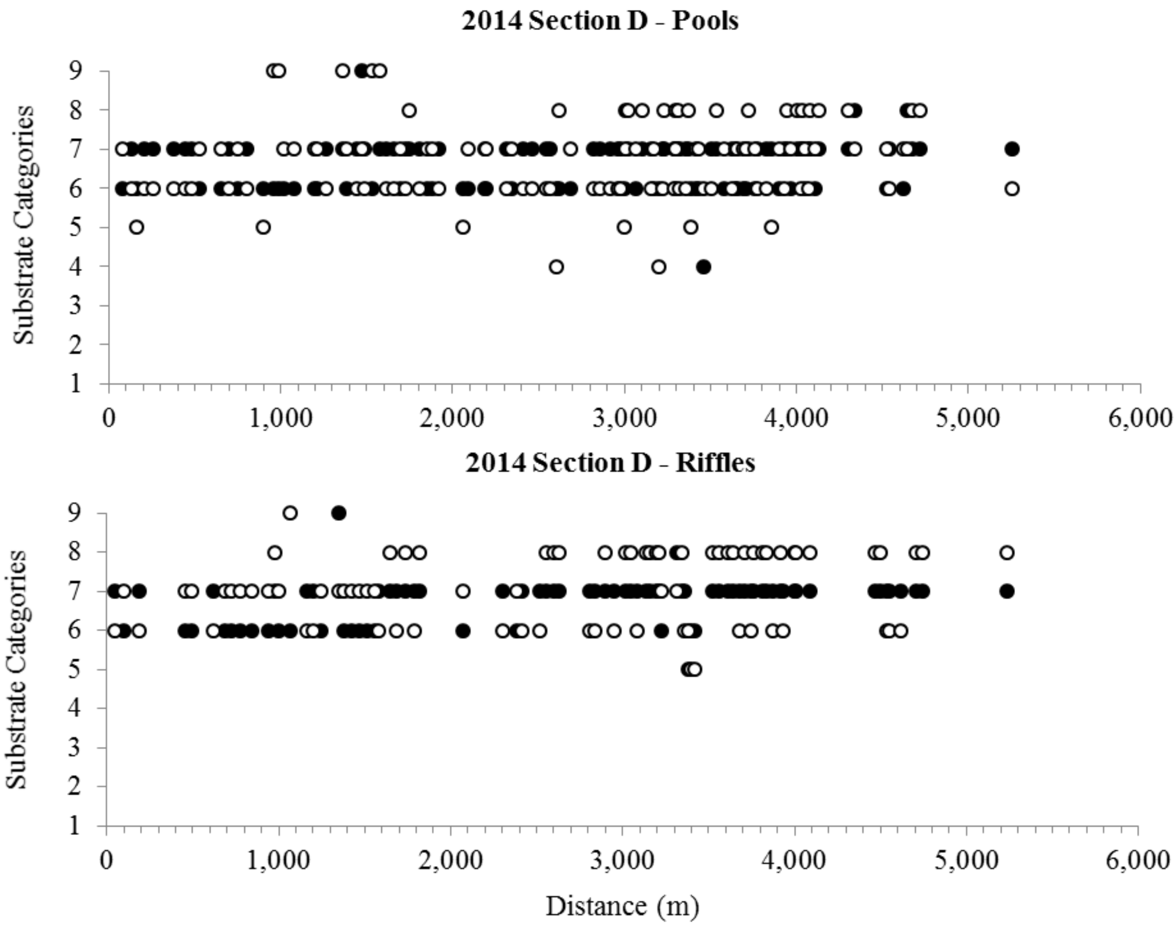


Figure 11. Dominant (solid circles) and subdominant (open circles) substrate category present in each pool (upper graph) and riffle (lower graph) within Section D in 2014. Substrate size categories: <u>1 Organic Matter</u> = dead leaves, detritus, etc.; <u>2 Clay</u> = sticky, holds form; <u>3 Silt</u> = slippery, doesn't hold form; <u>4 Sand</u> = silt-2 mm; <u>5 Small Gravel</u> = 3-16 mm; <u>6 Large Gravel</u> = 17-64 mm; <u>7 Cobble</u> = 65-256 mm; <u>8 Boulder</u> = >256 mm; <u>9 Bedrock</u> = solid rock.

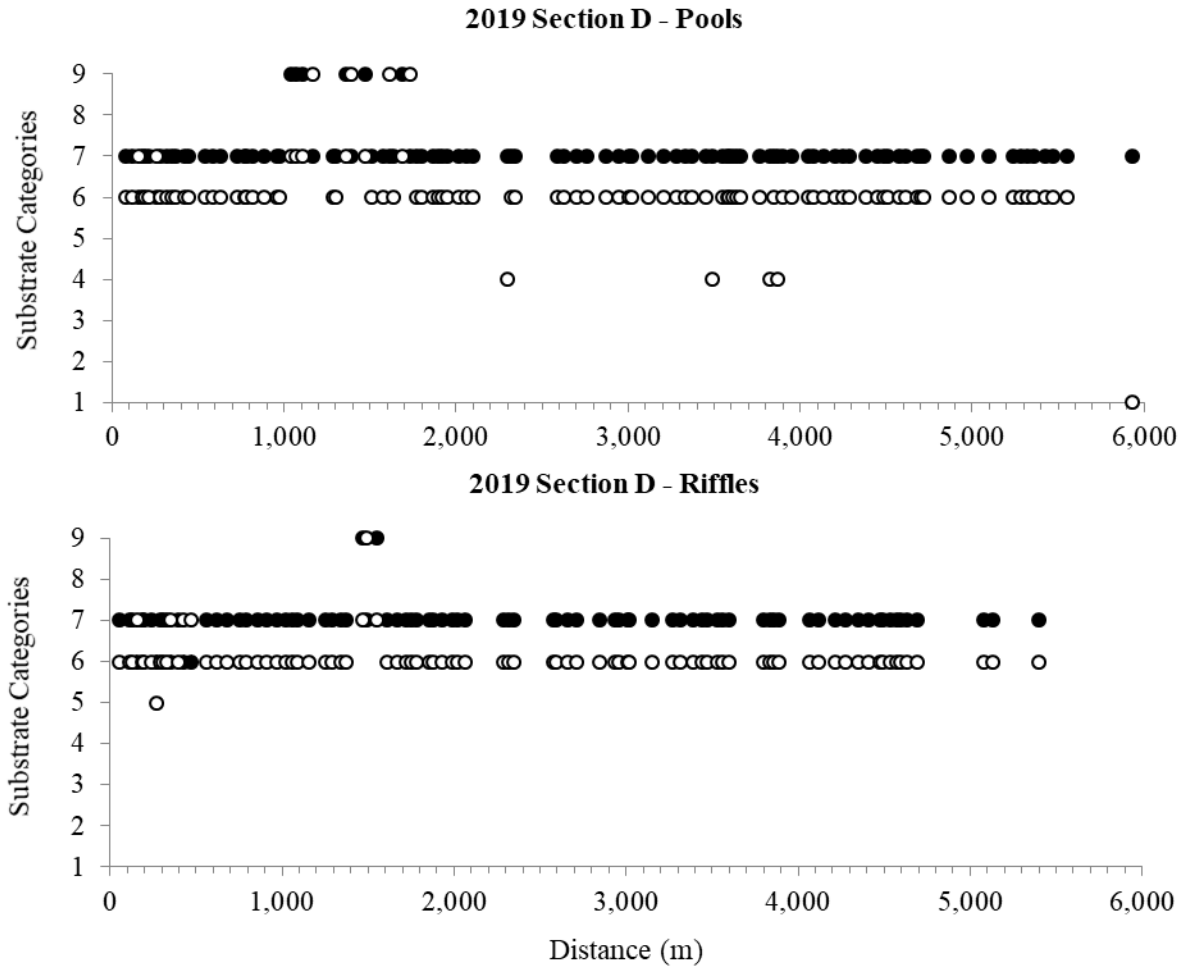


Figure 12. Dominant (solid circles) and subdominant (open circles) substrate category present in each pool (upper graph) and riffle (lower graph) within Section D in 2019. Substrate size categories: <u>1 Organic Matter</u> = dead leaves, detritus, etc.; <u>2 Clay</u> = sticky, holds form; <u>3 Silt</u> = slippery, doesn't hold form; <u>4 Sand</u> = silt-2 mm; <u>5 Small Gravel</u> = 3-16 mm; <u>6 Large Gravel</u> = 17-64 mm; <u>7 Cobble</u> = 65-256 mm; <u>8 Boulder</u> = >256 mm; <u>9 Bedrock</u> = solid rock.

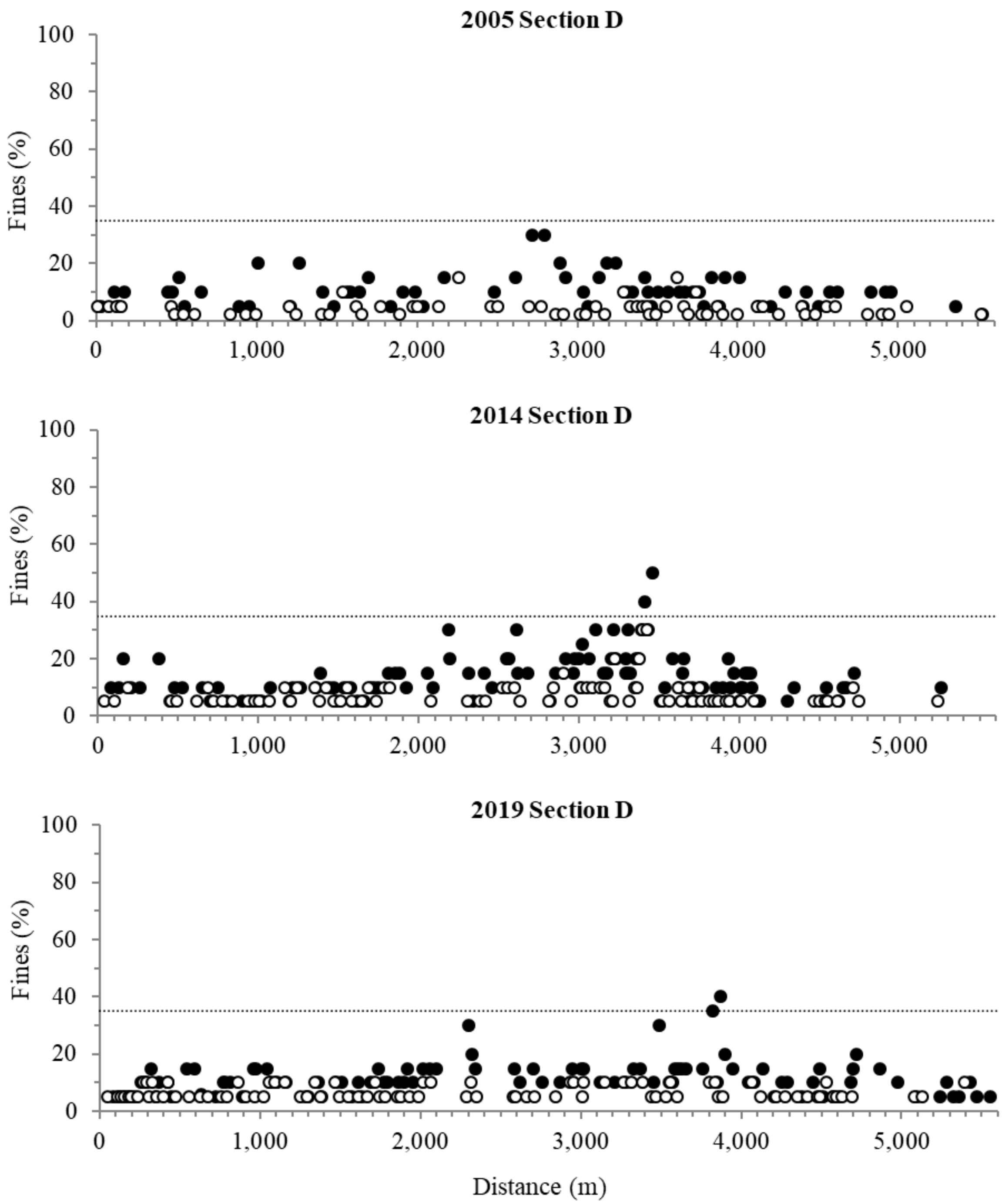


Figure 13. Percent of each pool (solid circles) and riffle (open circles) channel bottom comprised of fine sediment (sand, silt, and/or clay) within Section D in 2005, 2014, and 2019 (% fines data was not collected in 2002). Dashed line indicates 35% threshold at which fines can cause detrimental effects to stream fishes (Everest et al. 1987).

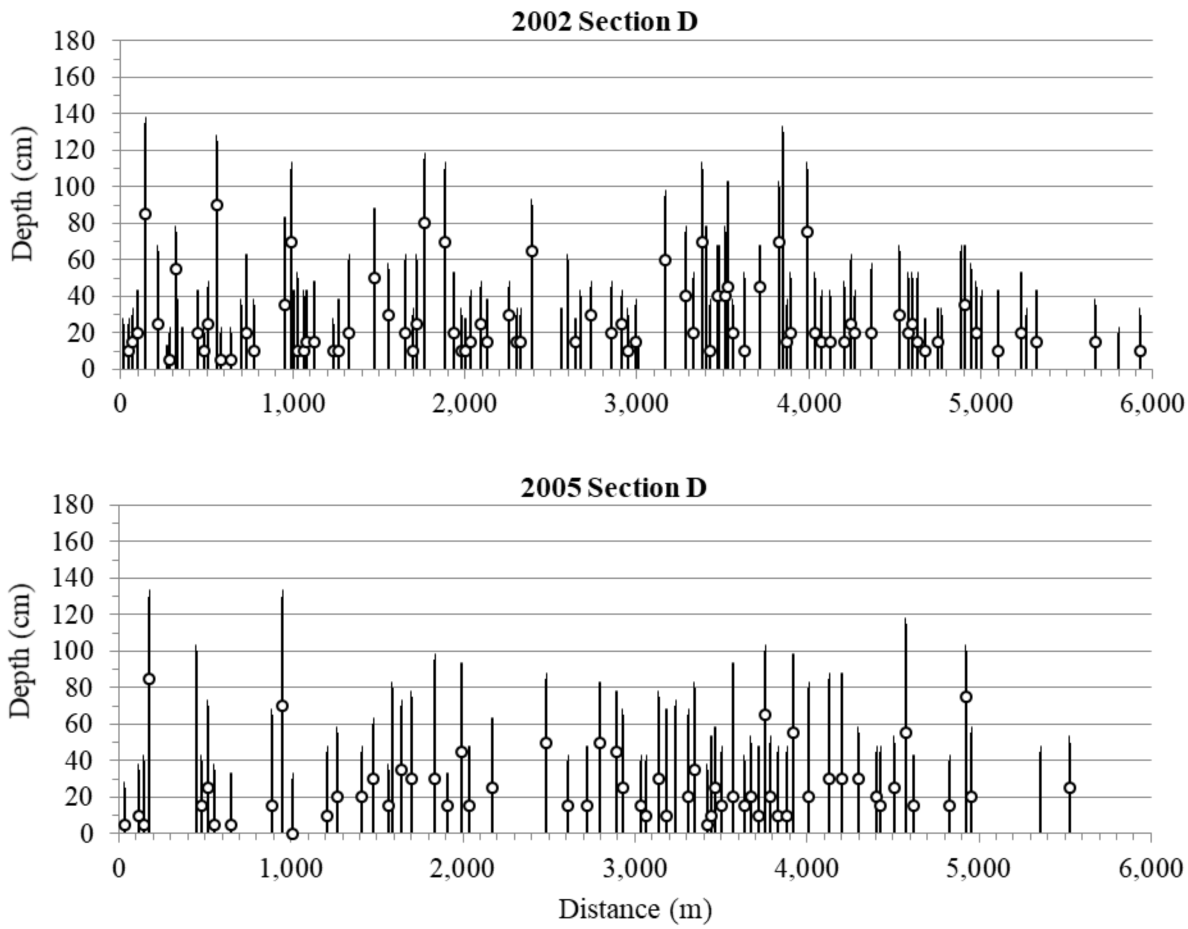


Figure 14. Maximum pool depth (bars) and residual pool depth (circles) shown longitudinally within Section D in 2002, 2005, 2014, and 2019 (figure continued on next page).

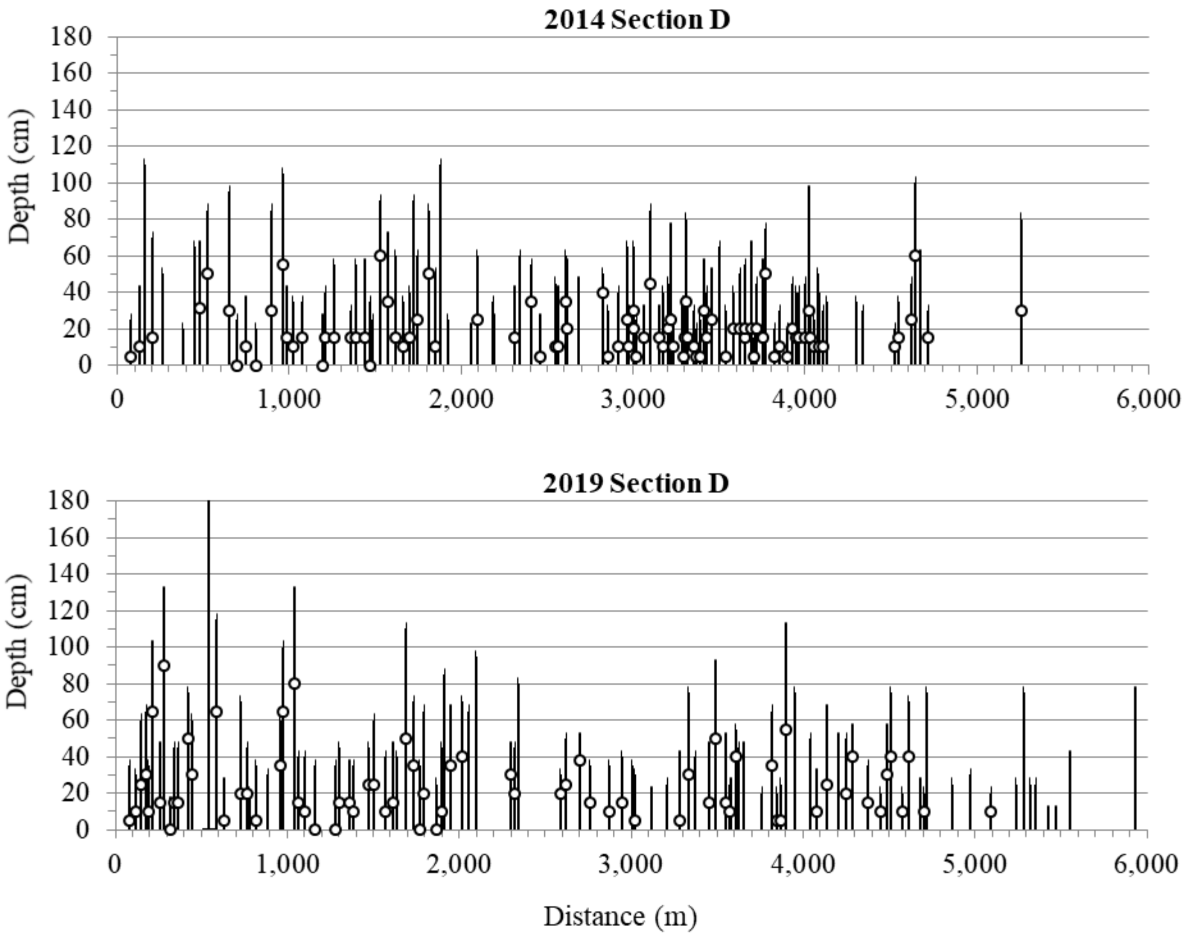


Figure 14 continued. Maximum pool depth (bars) and residual pool depth (circles) shown longitudinally within Section D in 2002, 2005, 2014, and 2019.

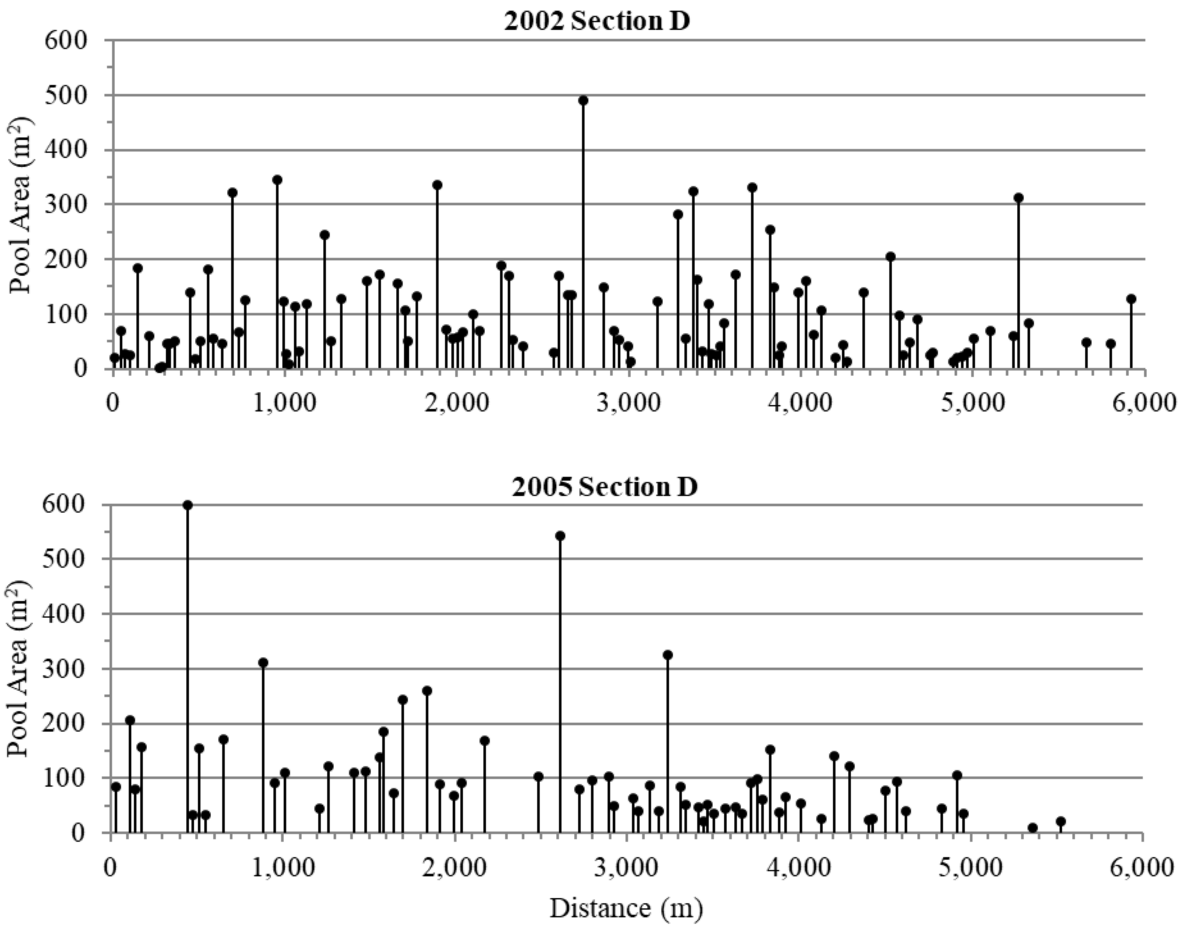
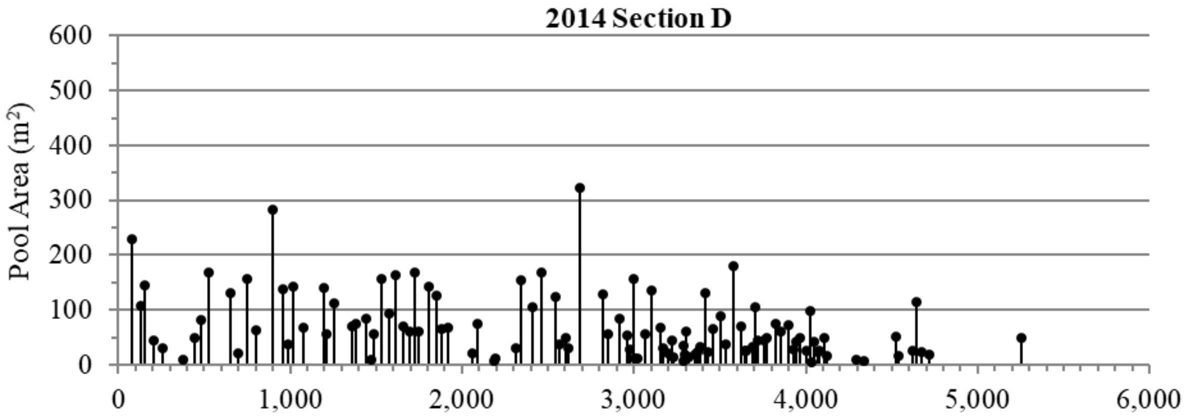


Figure 15. Pool area shown longitudinally within Section D in 2002, 2005, 2014, and 2019 (figure continued on next page).



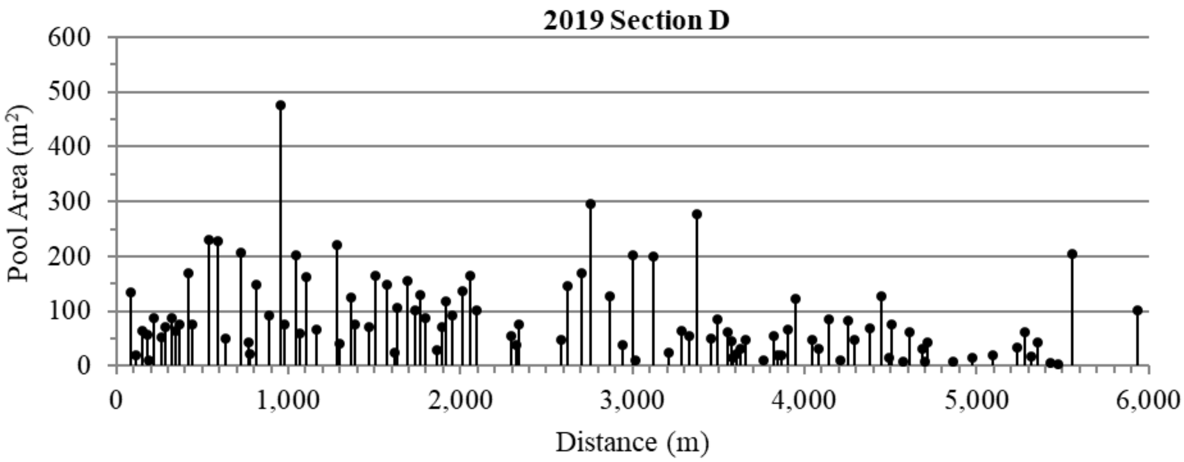


Figure 15 continued. Pool area shown longitudinally within Section D in 2002, 2005, 2014, and 2019.

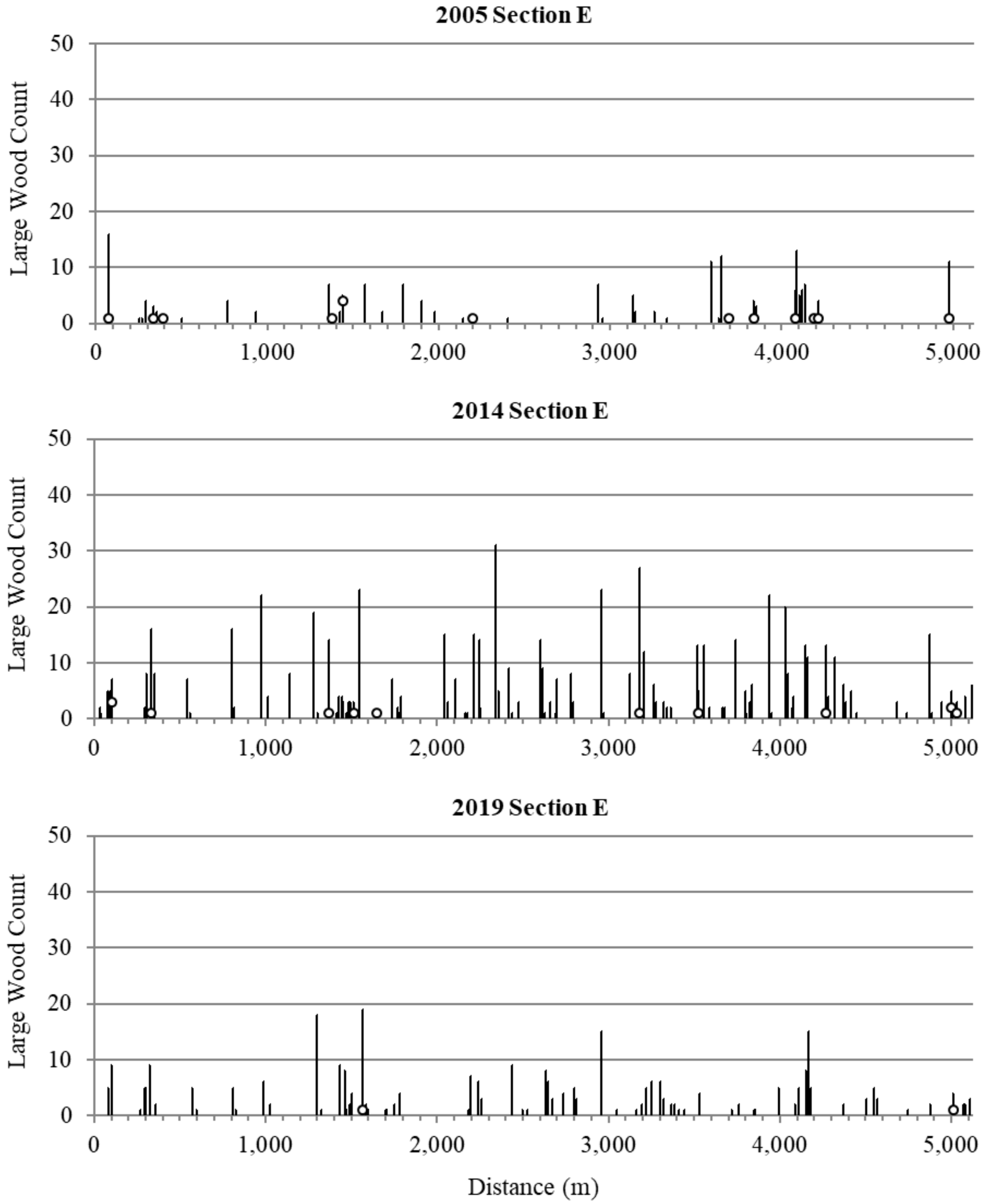


Figure 16. Count of large wood (bars = size classes 1, 2, 3, 4, and rootwad combined; open circles = size 4 only) within Section E in 2005, 2014, and 2019. Counts of large wood occurred within pools and riffles (counts within dry sections in 2014 and 2019 are excluded for comparison with prior years).

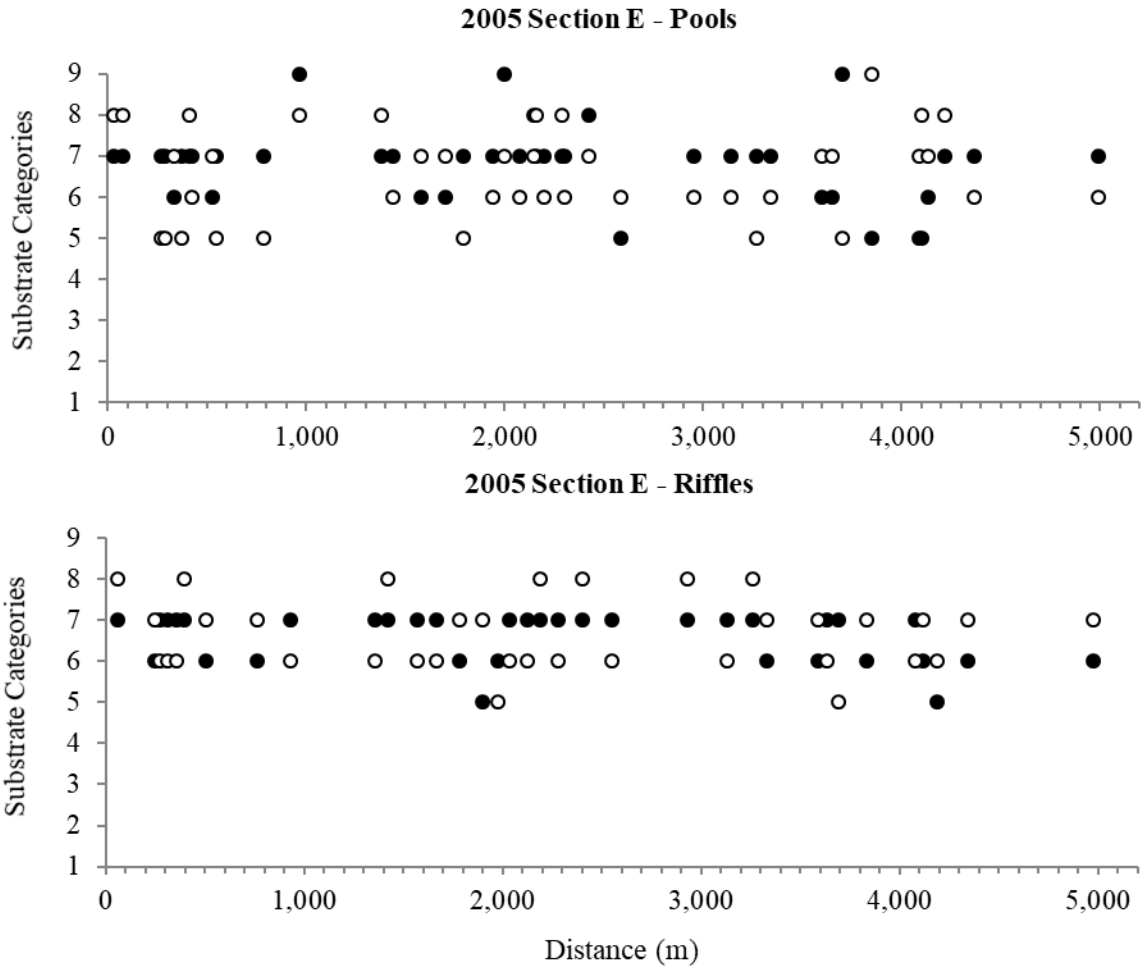


Figure 17. Dominant (solid circles) and subdominant (open circles) substrate category present in each pool (upper graph) and riffle (lower graph) within Section E in 2005. Substrate size categories: 1 Organic Matter = dead leaves, detritus, etc.; 2 Clay = sticky, holds form; 3 Silt = slippery, doesn't hold form; 4 Sand = silt-2 mm; 5 Small Gravel = 3-16 mm; 6 Large Gravel = 17-64 mm; 7 Cobble = 65-256 mm; 8 Boulder = >256 mm; 9 Bedrock = solid rock.

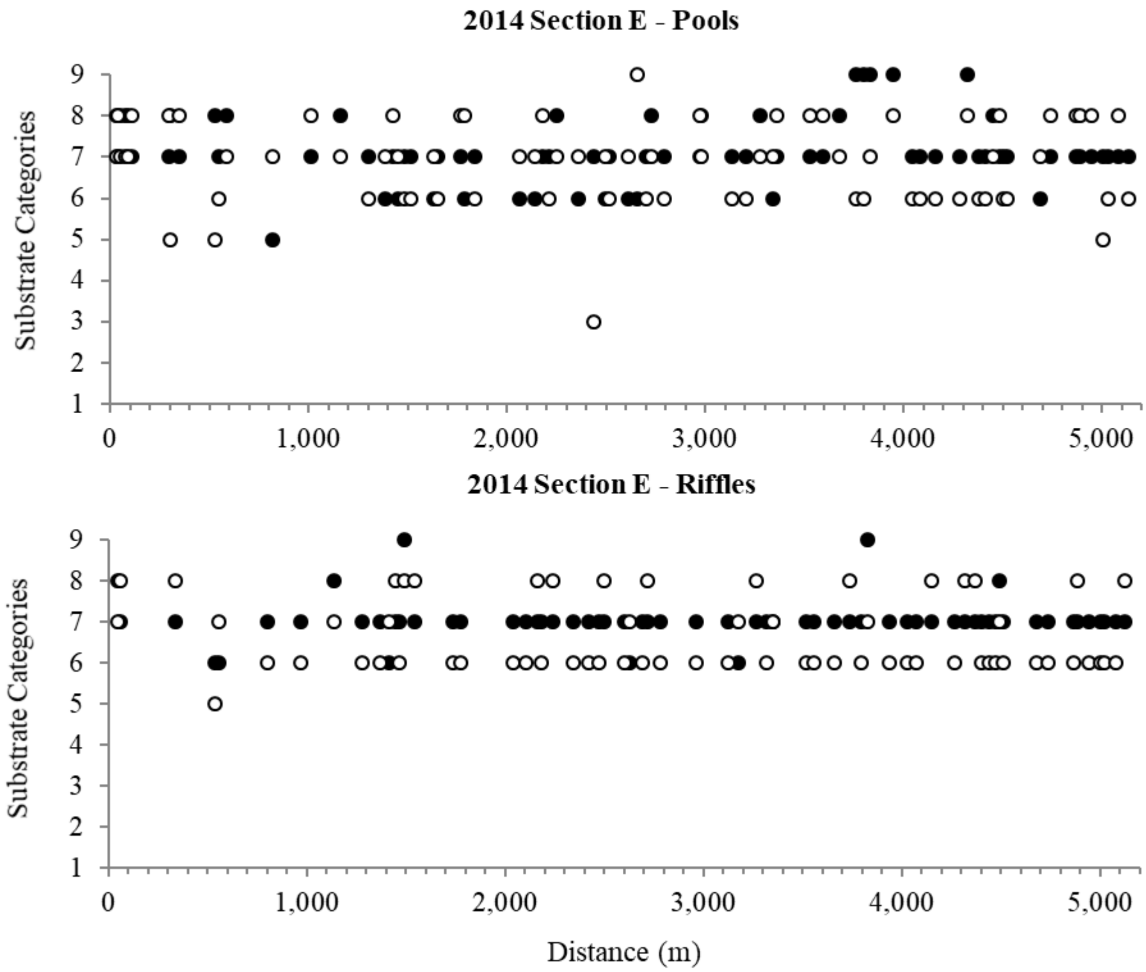


Figure 18. Dominant (solid circles) and subdominant (open circles) substrate category present in each pool (upper graph) and riffle (lower graph) within Section E in 2014. Substrate size categories: 1 Organic Matter = dead leaves, detritus, etc.; 2 Clay = sticky, holds form; 3 Silt = slippery, doesn't hold form; 4 Sand = silt-2 mm; 5 Small Gravel = 3-16 mm; 6 Large Gravel = 17-64 mm; 7 Cobble = 65-256 mm; 8 Boulder = >256 mm; 9 Bedrock = solid rock.

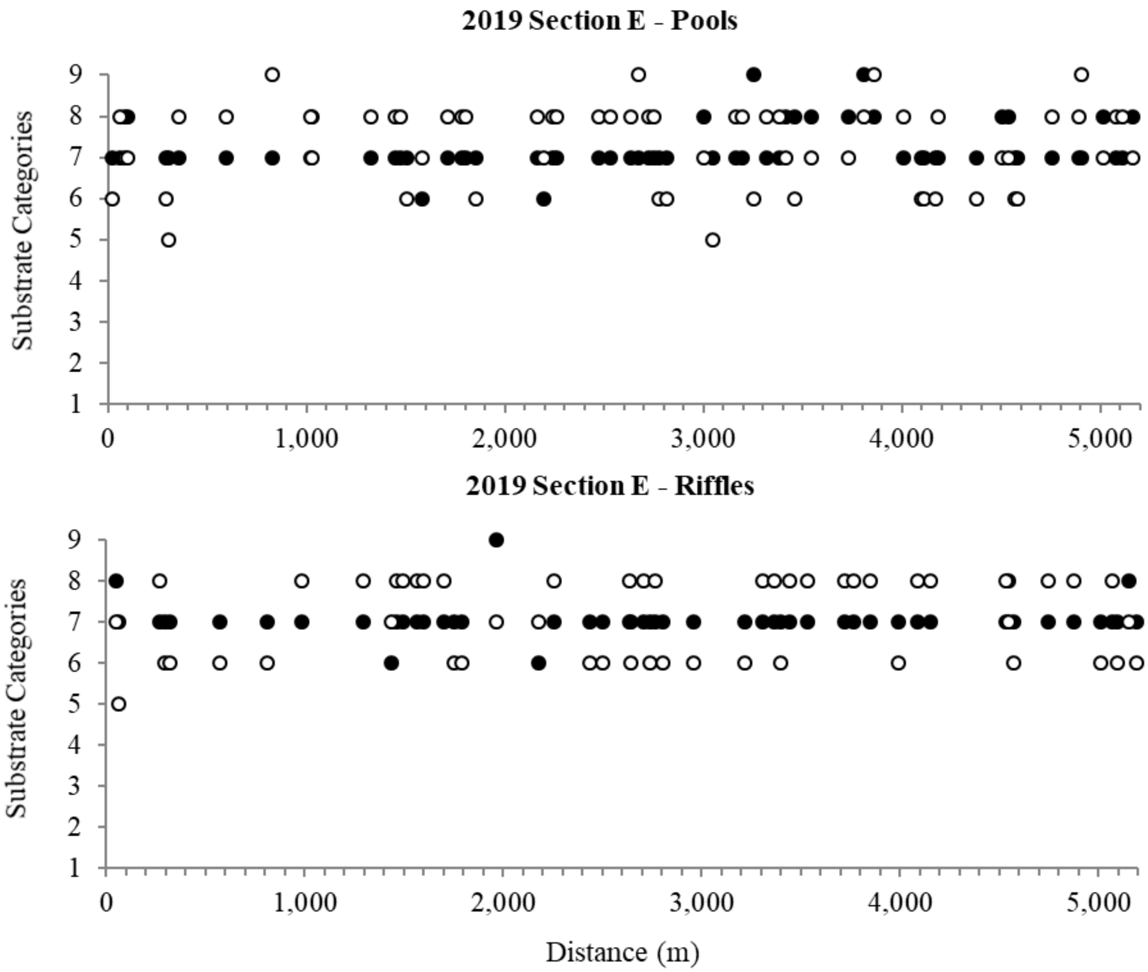


Figure 19. Dominant (solid circles) and subdominant (open circles) substrate category present in each pool (upper graph) and riffle (lower graph) within Section E in 2019. Substrate size categories: 1 Organic Matter = dead leaves, detritus, etc.; 2 Clay = sticky, holds form; 3 Silt = slippery, doesn't hold form; 4 Sand = silt-2 mm; 5 Small Gravel = 3-16 mm; 6 Large Gravel = 17-64 mm; 7 Cobble = 65-256 mm; 8 Boulder = >256 mm; 9 Bedrock = solid rock.

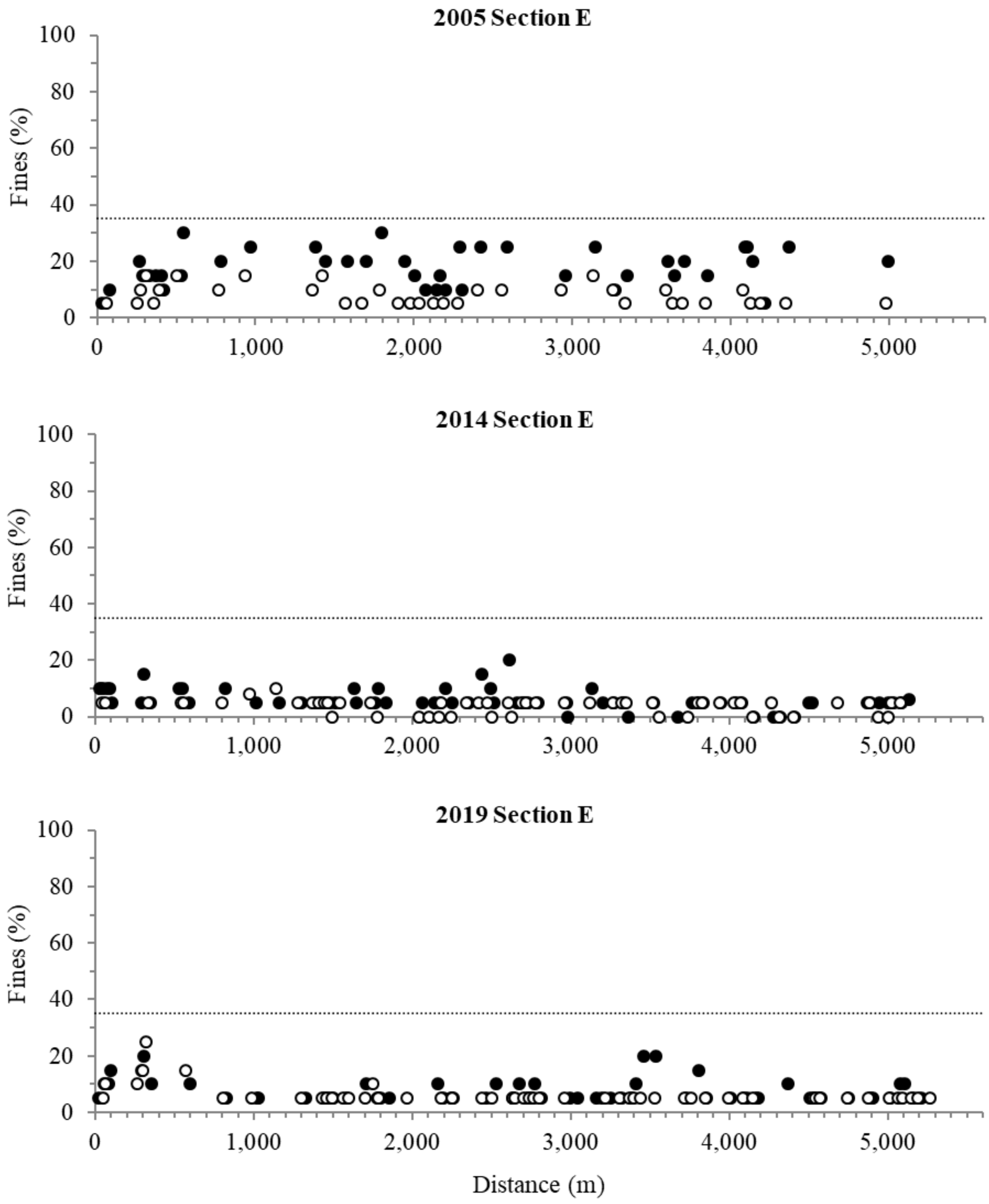


Figure 20. Percent of each pool (solid circles) and riffle (open circles) channel bottom comprised of fine sediment (sand, silt, and/or clay) within Section E in 2005, 2014, and 2019. Dashed line indicates 35% threshold at which fines can cause detrimental effects to stream fishes (Everest et al. 1987).

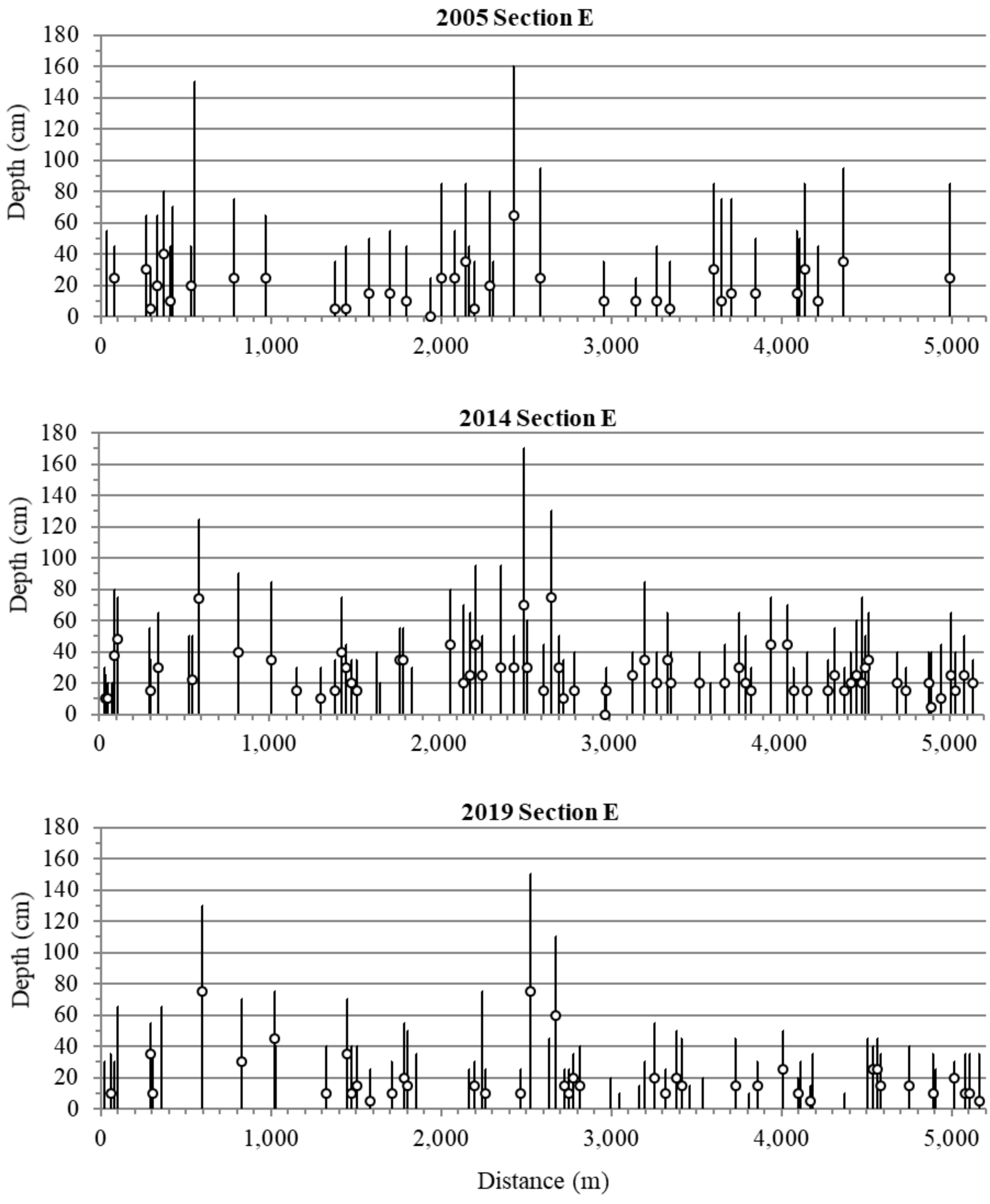


Figure 21. Maximum pool depth (bars) and residual pool depth (circles) shown longitudinally within Section E in 2005, 2014, and 2019.

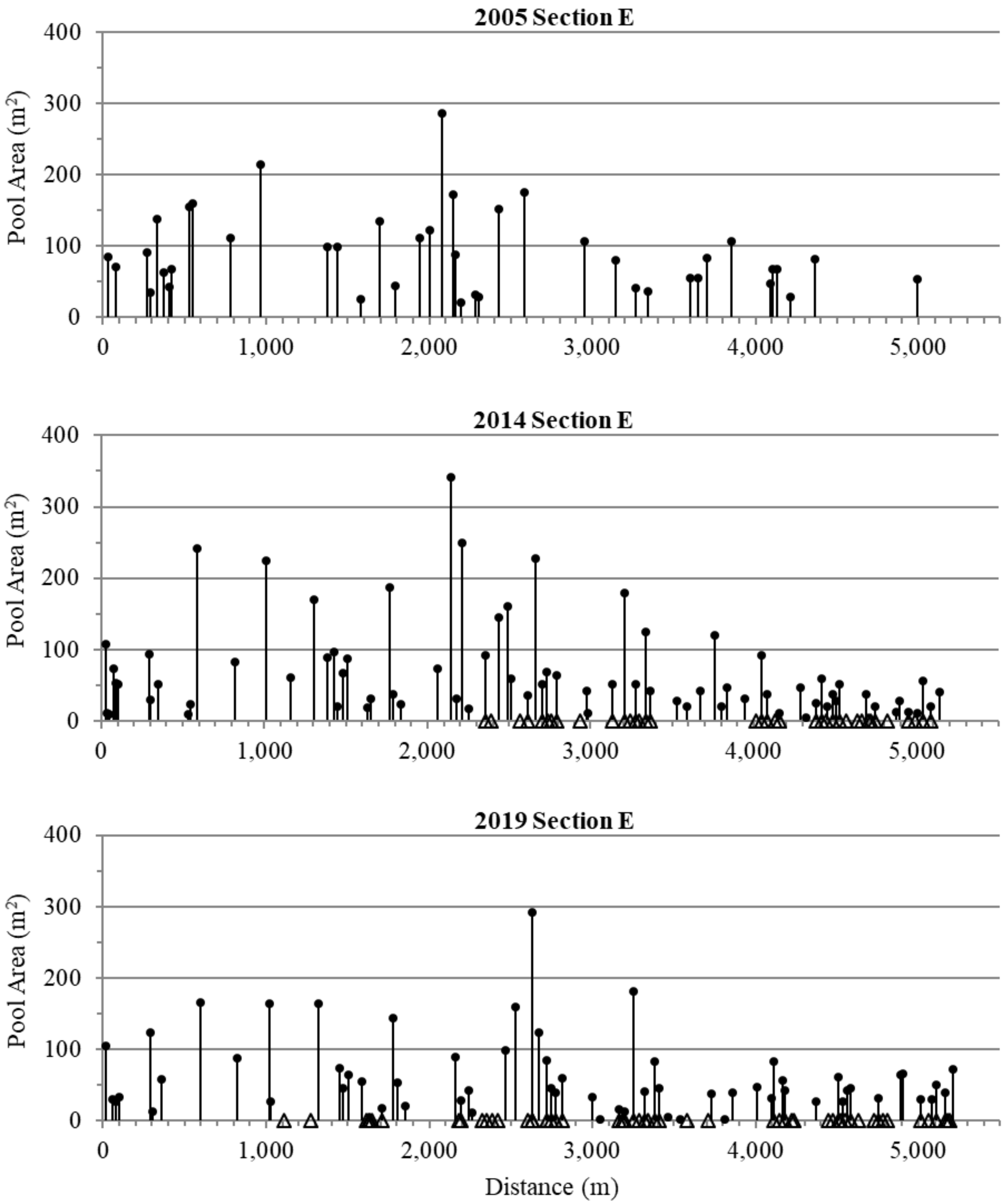


Figure 22. Pool area shown longitudinally within Section E in 2005, 2014, and 2019. Triangles indicate the locations of observed restoration structures.

Table 1. Summary of BVET inventories on the North River Sections D and E, North River Ranger District, George Washington Jefferson National Forest, VA.

North River Section	Topo Quad	Start Location	End Location	Date Start	Date End	BVET habitat (km)*	Constructed Restoration Structure Qty.	Field Observed Structure Qty.
Section D	Stokesville	Confluence with Elkhorn Lake N38.32935 W79.23186	Rd. 95 bridge near Rd. 528 N38.36389 W79.26726	6/24/2002	6/25/2002	5.9	0	0
				6/30/2005	7/1/2005	5.5	0	0
				8/19/2014	8/20/2014	5.3	0	0
				9/17/2019	9/18/2019	5.9	4	3
Section E	West August	Rd. 95 bridge near Rd. 528 N38.36407 W79.26740	Confluence with Little River N38.40080 W79.28371	6/30/2005	7/1/2005	5.0	0	0
				8/19/2014	8/20/2014	5.1	65	37
				9/17/2019	9/18/2019	5.3	96	53

**difference in inventoried BVET habitat distance is due to variability in measurement, not different start or end locations*

Table 2. Quantity of restoration structures installed between 2005-2017 in North River Sections D and E.

North River Section	2005*	2006	2007	2008	2009	2010	2012	2013	2015	2016	2017	Total
Section D											4	4
Section E	10	7	4	2	18	10	9	5	15	16		96

**2005 structures were installed in August-September 2005, after the June-July 2005 BVET*

Table 3. Flow (cfs) on each day BVET data was inventoried (USGS flow gage #01620500, North River near Stokesville, VA).

Daily Mean Discharge			
Day 1		Day 2	
June 24, 2002	1.5 cfs	June 25, 2002	2.0 cfs
June 30, 2005	1.4 cfs	July 1, 2005	2.1 cfs
August 19, 2014	1.3 cfs	August 20, 2014	1.6 cfs
September 17, 2019	1.2 cfs	September 18, 2019	1.2 cfs

Table 4. Stream area in pools and riffles as observed during BVET habitat inventories of Sections D and E.

		Habitat Area (m^2)					% Wetted		% Total Area			Unit Count		
North River Section	Year	Pool	Riffle	Dry**	Wetted Area	Total Area	Pool	Riffle	Pool	Riffle	Dry	Pools + Glides = Slow Water Unit Qty.	Riffles + Runs = Fast Water Unit Qty.	Dry Reach Qty.
Section D	2002	10,335	13,912	5,156	24,248	29,404	43%	57%	35%	47%	18%	92+9 = 101	82+2 = 84	23
	2005	7,328	18,249	2,271	25,577	27,848	29%	71%	26%	66%	8%	60+5 = 65	65+2 = 64	4
	2014	7,764	11,604	5,744	19,368	25,112	40%	60%	31%	46%	23%	89+21 = 110	79+0 = 79	21
	2019*	8,933	7,848	4,386	16,781	21,167	53%	47%	42%	37%	21%	69+34 = 103	83+3 = 86	25
Section E	2005	3,736	24,432	350	28,168	28,518	13%	87%	13%	86%	1%	28+13 = 41	35+0 = 35	4
	2014*	5,019	16,182	3,434	21,201	24,635	24%	76%	20%	66%	14%	60+14 = 74	64+0 = 64	9
	2019*	3,905	12,290	7,880	16,195	24,075	24%	76%	16%	51%	33%	46+17 = 63	52+0 = 52	23

**restoration structures present*
***dry area calculated using average wetted riffle width because widths were not measured for dry sections*

Table 5. Large wood (LW) per kilometer observed during BVET habitat inventories of Sections D and E. LW size classes: LW1 = 1-5 m length, 10-55 cm diameter; LW2 = 1-5 m length, >55 cm diameter; LW3 = >5 m length, 10-55 cm diameter; LW4 = >5 m length, >55 cm diameter; RW = rootwad (counts within dry sections in 2014 and 2019 are excluded for comparison with prior years) .

North River Section	Year	Large Wood per Km						Large Wood Count in Sample Reach						Inventory Distance (km)
		LW1/ km	LW2/ km	LW3/ km	LW4/ km	RW/ km	Total LW/km	LW1 n	LW2 n	LW3 n	LW4 n	RW n	Total LW n	
Section D	2002	46	0	15	0	NA	61	271	1	87	2	NA	361	5.9
	2005	2	1	10	2	6	22	13	7	58	11	31	120	5.5
	2014	48	1	49	1	28	127	254	5	255	7	147	668	5.3
	2019*	8	0	30	1	14	53	47	0	179	5	86	317	5.9
Section E	2005	13	1	15	3	3	36	67	3	77	15	16	178	5.0
	2014*	54	1	59	3	19	134	276	3	302	13	96	690	5.1
	2019*	30	0	14	0	15	59	157	1	72	2	81	313	5.3

**restoration structures present*

Table 6. Percent occurrence of dominant and subdominant substrate size categories in pools and riffles in Sections D and E. See appendix A for substrate size categories.

		Pool Dominant Substrate									Riffle Dominant Substrate								
North River Section	Year	Organic M.	Clay	Silt	Sand	Small G.	Large G.	Cobble	Boulder	Bedrock	Organic M.	Clay	Silt	Sand	Small G.	Large G.	Cobble	Boulder	Bedrock
Section D	2002	0%	0%	0%	0%	1%	80%	14%	0%	5%	0%	0%	0%	0%	0%	62%	36%	0%	2%
	2005	0%	0%	0%	0%	0%	48%	48%	0%	5%	0%	0%	0%	0%	0%	30%	70%	0%	0%
	2014	0%	0%	0%	1%	0%	41%	55%	3%	1%	0%	0%	0%	0%	1%	27%	70%	1%	1%
	2019	0%	0%	0%	0%	0%	2%	92%	0%	6%	0%	0%	0%	0%	0%	6%	92%	0%	2%
Section E	2005	0%	0%	0%	0%	10%	17%	61%	5%	7%	0%	0%	0%	0%	6%	31%	63%	0%	0%
	2014	0%	0%	0%	0%	1%	16%	57%	19%	7%	0%	0%	0%	0%	0%	8%	84%	5%	3%
	2019	0%	0%	0%	0%	0%	3%	73%	21%	3%	0%	0%	0%	0%	0%	4%	88%	6%	2%

		Pool Subdominant Substrate									Riffle Subdominant Substrate								
	Year	Organic M.	Clay	Silt	Sand	Small G.	Large G.	Cobble	Boulder	Bedrock	Organic M.	Clay	Silt	Sand	Small G.	Large G.	Cobble	Boulder	Bedrock
Section D	2002	4%	0%	0%	0%	0%	5%	77%	14%	0%	0%	0%	0%	0%	0%	1%	63%	36%	0%
	2005	0%	0%	0%	0%	0%	35%	49%	6%	9%	0%	0%	0%	0%	0%	56%	30%	13%	2%
	2014	0%	0%	0%	2%	5%	37%	35%	16%	5%	0%	0%	0%	0%	3%	30%	25%	41%	1%
	2019	1%	0%	0%	4%	0%	83%	8%	0%	4%	0%	0%	0%	0%	1%	91%	7%	0%	1%
Section E	2005	0%	0%	0%	0%	20%	29%	27%	22%	2%	0%	0%	0%	0%	6%	43%	31%	20%	0%
	2014	0%	0%	1%	0%	4%	32%	32%	28%	1%	0%	0%	0%	0%	2%	59%	14%	25%	0%
	2019	0%	0%	0%	0%	3%	24%	21%	46%	6%	0%	0%	0%	0%	2%	38%	12%	48%	0%

Table 7. Summary of BVET stream habitat attribute averages collected in Sections D and E.

North River Section	Year	Mean Avg. Depth (cm)		Mean Max. Depth (cm)		Mean Residual Pool Depth (cm)**	Avg. Wetted Width (m)		Avg. % Fines		Rosgen
		Pools	Riffles	Pools	Riffles		Pools	Riffles	Pools	Riffles	
Section D	2002	35	13	51	20	26	4.3	4.7	NA	NA	B,C
	2005	35	10	61	20	25	4.3	5.1	11	4	C
	2014	28	11	47	18	19	4.4	4.5	14	8	C,F
	2019*	32	7	51	17	23	4.3	2.8	12	7	C,F
Section E	2005	33	13	62	24	19	4.8	5.0	18	8	B,C
	2014*	32	9	53	21	26	4.4	4.3	6	4	C,F
	2019*	25	8	41	20	20	3.6	4.0	7	6	C,F

**restoration structures present*
***residual pool depth = average pool depth – riffle crest depth*

Appendix A: Field Methods for Stream Habitat Inventory

Guide to Stream Habitat Characterization using the BVET Methodology in the George Washington Jefferson National Forest, VA

Prepared by:

CENTER FOR AQUATIC TECHNOLOGY TRANSFER
CATT

Prepared by: Colin Krause and Craig N. Roghair

2014

Table of Contents

Introduction

The basinwide visual estimation technique (BVET) is a versatile tool used to assess streamwide habitat conditions in wadeable size streams and rivers. A crew of two individuals performs the inventory using two-stage visual estimation techniques described in Hankin and Reeves (1988) and Dolloff et al. (1993). In its most basic form the BVET combines visual estimates with actual measurements to provide a calibrated estimate of stream area with confidence intervals, however the crew may inventory any number of other habitat attributes as they walk length of the stream. Experienced crews can inventory an average of 2.0 – 3.0 km per day, but this will vary depending on stream size and the number of stream attributes inventoried.

Before a crew begins a BVET inventory they must receive adequate training, both in the classroom and in the field. Estimating and measuring a large number of habitat attributes can confuse and overwhelm an inexperienced crew. Individuals must have an understanding of the basic concepts behind the BVET and be familiar with habitat attributes before they can effectively and efficiently perform an inventory.

The USFS Center for Aquatic Technology Transfer (CATT) has been working directly with resource managers on the George Washington Jefferson National Forest (GWJNF) since the mid 1990's to implement BVET inventories and adapt them to the Forest's specific needs. More than 10 habitat attributes are currently estimated or measured during GWJNF BVET habitat inventories. We review the inventory annually and add and remove attributes as needed to maximize efficiency and relevancy with regards to emerging techniques and Forest issues. Changes are made only after careful review to ensure consistency with data collected in the past. Habitat surveys performed in 2004 followed methods identical to those used in National Forests in Virginia and changes to that survey are described in the 'Changes to BVET inventory in 2014' section.

This document was developed to serve as a guide for classroom and field instruction specific to the GWJNF BVET habitat inventory and to provide a post-training reference for field crews. It includes an overview of the BVET inventory, defines habitat attributes, instructs how and when to measure attributes, and provides reference sheets for use in the field. Each trainee should receive a copy of this manual and is encouraged to take notes in the spaces provided.

References cited in this manual:

Armantrout, N. B., compiler. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. General Technical Report SE-83. Asheville, North Carolina: U.S. Department of Agriculture, Southeastern Forest Experimental Station.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.

Changes to BVET inventory in 2014

Attribute	Action	Reason
Start & End	Modified	The start and end location of the survey is a defined reach chosen by the GWJNF biologist.
Features	Modified	Rosgen measurements added; including bankfull channel width, max and average bankfull depth, left and right riparian width, gradient, and water temperature.

Other minor changes, mostly modifications in terminology and definitions to provide increased clarity, are found throughout the manual.

Outline of BVET Habitat Inventory

The inventory is comprised of the following steps:

1) Enter 'header' information in the data sheet
    - 'Header' information includes date, stream, start location, crew, etc. and is **vitally** important to record for future reference

2) Select an appropriate measurement interval and a random number
    - In streams < 1.0 km measure every 5th unit (random number 1-5), in streams > 1.0 km measure every 10th unit (random number 1-10)
    - The random number designates the first habitat unit (i.e. the paired sample unit) in which the crew will perform measurements

3) Enter downstream of the starting point, then move upstream and begin the inventory
    - Tie off the hipchain, proceed upstream to the starting point, reset the hipchain to zero, and proceed upstream estimating parameters and recording data in every habitat unit

4) At the paired sample unit perform visual estimates, then perform measurements
    - If the random number '3' were chosen, the crew would stop after making estimates in the 3rd pool (and 3rd riffle) and perform the necessary measurements

5) Progress upstream estimating attributes for every unit until the next paired sample unit is reached, then repeat step 4
    - In the above example, if the interval were 10 units, the crew would stop at the 13th, 23rd, 33rd, etc. pool (and 13th, 23rd, 33rd, etc. riffle) and repeat measurements done in pool 3 and riffle 3.
    - The crew should also take care to record roads, trails, tributaries, dams, waterfalls, road crossing types, riparian features (wildlife openings, trails, campsites, roads, timber harvest, etc.), and other pertinent stream features as they progress upstream. Be sure to record hipchain distances when noting such features.

Repeat steps 4 and 5 until the end of the stream is reached.

The following sections describe the BVET habitat inventory in detail:

Section 1: Getting Started – equipment lists, header information, random numbers, starting the inventory

Section 2: Habitat Attributes – definitions, how to estimate or measure, when to record

Section 3: Wrapping Up – what to do when the inventory is completed

Appendix: field guide, random number tables, equipment checklist

Section 1: Getting Started

Equipment List

Hipchain	backpack
extra string for hipchain	pencils
wading rod	flagging
50 m tape measure	markers
Datalogger	waterproof backup datasheets
GPS unit	BVET manual and field guide
topographic map	felt bottom wading boots or waders
camera	

Other useful equipment: lunch, water, water filter, 1st aid kit, toilet paper, rain gear, radio/cell phone

The crew consists of two individuals, the 'observer' and the 'recorder'. The observer wears the hipchain and carries the wading rod. The recorder wears the data logger and carries other equipment in the backpack. The duties of each individual are listed below.

Duties

Observer	Recorder
Determine NHD_ID	Locate changes in NHD_ID
Designate habitat units	Record data
Measure distance	Determine paired sample location
Estimate width	Classify and count LW
Estimate depths	Photo-documentation
Classify substrates	Document features
Estimate percent fines	

Both crew members are needed to measure actual widths, channel widths, riparian areas, gradient, and water temperature at designated units. Although the crew has assigned duties, they should not hesitate to consult with each other if they have questions or feel that a mistake may have been made. Working as a team will provide the best possible results.

Header Information

Header information is **vitally important** for future reference. Take the time to record all categories completely and accurately.

Stream Name	Full name of stream
District	National Forest District name
Quad	USGS 1:24,000 quadrangle name
Date	Record date(s) of inventory
Recorder	Full name of recorder
Observer	Full name of observer
GPS	record at start and end locations, always use NAD27 CONUS, UTM
Location	**Detailed** written description of start point, include landmarks, road #, etc.
Notes	Record signs of activity in area, water conditions, other pertinent information

Random Numbers

Before beginning the inventory, select a number from a random numbers table (see Appendix) to determine the first habitat unit at which to make measurements. For long inventories (> 1.0 km) select a random number between 1 and 10th (i.e. measure every 10 unit), for shorter streams use a number between 1 and 5 (i.e. measure every 5th unit). See the appendix for random numbers tables.

The crew needs to measure units more frequently during shorter inventories to provide enough 'paired samples' for data analysis. 'Paired samples' are habitat units in which both visual estimates and actual measurements are made. The more paired samples, the tighter the confidence intervals for stream area estimates.

After the crew records a paired sample they continue upstream making visual estimates and stopping to make additional measurements at the pre-determined interval. For example, if the random number was 3 and the crew was measuring every 5th unit, the crew would make measurements on the 3rd pool and 3rd riffle and then every 5th pool and riffle thereafter (8, 13, 18, 23, etc).

Starting the Inventory

After the crew has organized their gear, determined their measurement interval, selected a random number, recorded all the header information, and determined the starting NHD_ID they are ready to begin the habitat inventory. The observer should enter the stream slightly downstream of the starting point, tie off the hipchain, progress upstream to the starting point, reset the hipchain to zero and begin walking upstream through the first habitat unit. As the observer moves upstream they use the wading rod to measure depth at several locations in the habitat unit and make observations of unit type, width, substrates, and percent fines. When they reach the upstream end of the habitat unit they stop, report the distance, then turn to face the unit and report the unit type, estimated width, maximum and average depth, riffle crest depth (where appropriate), dominant and subdominant substrate classes, and percent fines to the recorder.

As the observer moves upstream through the unit, the recorder follows behind, recording the amount of LW in the habitat unit. The recorder also assigns a number to the habitat unit. The recorder tells the observer if a unit is designated for measurements (i.e. if it is a 'paired sample' unit) only after they have recorded visual estimates.

The crew continues upstream making estimates in every habitat unit and making estimates and measurements in every paired sample unit until the inventory endpoint is reached. The crew needs to keep track of their location carefully to determine when they enter a new NHD_ID reach.

Definitions of habitat attributes, how to measure and when to record them, and what to do when the inventory is complete are covered in the following sections.

Section 2: Stream Attributes

NHD_ID (see map for ID number)

Definition:
Stream reach identification number assigned in the National Hydrography Dataset (NHD). A map delineating stream reaches with corresponding reach numbers is provided by the Forest prior to the start of the inventory.

How to estimate:
At the beginning of the inventory the crew determines the starting NHD_ID number from the provided maps. As the crew moves upstream they must carefully track their location and change the NHD_ID number when they move into a new NHD stream reach.

When to record: every habitat unit

Unit Type (see abbreviations)

Definitions:*

Unit Type	Abbreviation	Definition
Riffle	**R**	**Fast water, turbulent, gradient <12%**; shallow reaches characterized by water flowing over or around rough bed materials that break the surface during low flows; also **include rapids** (turbulent with intermittent whitewater, breaking waves, and exposed boulders), **chutes** (rapidly flowing water within narrow, steep slots of bedrock), and **sheets** (shallow water flowing over bedrock) if gradient <12%
Cascade	**C**	**Fast water, turbulent, gradient ≥12%**; highly turbulent series of short falls and small scour basins, with very rapid water movement; also **include sheets** (shallow water flowing over bedrock) and **chutes** (rapidly flowing water within narrow, steep slots of bedrock) if gradient ≥12%
Run	**RN**	**Fast water, non-turbulent, gradient <12%**; deeper than riffles with little or no surface agitation or flow obstructions and a flat bottom profile
Pool	**P**	**Slow water, surface turbulence may or may not be present, gradient <1%**; generally deeper and wider than habitat immediately upstream and downstream, concave bottom profile; **includes dammed pools, scour pools, and plunge pools**
Glide	**G**	**Slow water, no surface turbulence, gradient <1%**; shallow with little to no flow and flat bottom profile
Underground	**UNGR**	Stream channel is dry or not containing enough water to form distinguishable habitat units

*modified from Armantrout (1998)

How to estimate:
Habitat units are separated by 'breaks'. Breaks can be obvious physical barriers, such as a debris dam separating two pools or a small waterfall separating a pool and riffle, or may be less obvious transitional areas. Questions often arise as to whether a break is substantial enough to split two habitat units and where the exact location of the break occurs. When in doubt, the observer should consult with the recorder and the team should 'think like a fish'. To determine if a break should be made, consider whether a fish would have to make an effort to move across the break and into the next habitat unit. If not, then it is probably a single habitat unit.

The channel may have both pool and riffle type habitat in the same cross-sectional area. Determine the predominate habitat type and record it as the unit type. For example if an area contains both pool and riffle, but the majority of the flow is into and out of the pool habitat, then call a pool.

Questions also often arise as to the minimum size of individual habitat units. Generally, if a habitat unit is not at least as long as the wetted channel is wide, then do not count it as a separate habitat unit. This rule may need to be adjusted for streams wider than 5 m. Use best professional judgment in such cases.

See the section 2.1 for a list of features that should also be recorded while performing the inventory.

When to record: every habitat unit

Unit Number (#)

Definition:
Count of habitat units of similar types, used to determine location of paired sample units

How to estimate:
When counting habitat units, group pools and glides (slow water) together, and group riffles, runs, and cascades (fast water) together. For example, consider the following sequence of habitat units:

Pool – Riffle – Pool – Pool – Riffle - Cascade – Riffle - Glide – Riffle – Pool – Run – Pool – Riffle

Habitat units in this sequence would be counted in the following manner (similar types are shaded same color):

Unit Type	Unit Number
P	1
R	1
P	2
P	3
R	2
C	3
R	4
G	4
R	5
P	5
RN	6
P	6
R	7

In the above example, the crew has counted six slow water (pool/glide) units and seven fast water (riffle/run/cascade) units.

If '3' were chosen as the random number and the measuring interval was every 10th unit, the crew would estimate and then measure habitat data for Pool 3 and Cascade 3 (i.e. Pool 3 and Cascade 3 are 'paired sample' units). When the crew reaches pool or glide 13 and riffle, run, or cascade 13, they would repeat procedures followed in the 3rd units.

When to record: every habitat unit; not recorded for features such as falls, tributaries, side channels, culverts, etc.

Distance (m)

Definition:
Number of meters from the start of the inventory to the upstream end of the habitat unit or distance from the start of the inventory to upstream end of a feature, used as spatial reference for data analysis and to locate features in the future.

How to estimate:
The observer walks upstream in the middle of the stream channel with a hipchain measuring device. When they reach the upstream break between habitat units or the upstream end of a feature they stop and report the distance to the recorder.

Care should be taken to keep the hipchain string in the middle of the stream, especially around bends and meanders. If the hipchain should break, retreat to the location where the break occurred, tie off the hipchain, and continue. If the hipchain is reset for any reason be sure to note it in the comments.

When to record: every habitat unit and feature

Estimated Width (m)

Definition:
Average wetted width of the habitat unit as estimated visually, used to calculate stream area. Wetted width is the distance from the edge of the water on one side of the main channel to the edge of the water on the opposite side of the main channel.

How to estimate:
The observer notes the general shape and width of the unit while walking to the upstream end. When they reach the upstream end of the unit the observer stops, turns to face the unit, and estimates the average wetted width. Measure the wetted width of the stream before starting each day to calibrate yourself.

When to record: every habitat unit

Maximum and Average Depth (cm)

Definitions:
Maximum Depth – vertical distance from substrate to water surface at deepest point in habitat unit
Average Depth – average vertical distance from substrate to water surface in habitat unit

How to estimate:
The observer uses a wading rod marked in 5 cm increments to measure water depth as they walk upstream through the habitat unit. Water depth in deepest spot is recorded as the maximum depth. Average depth is the average of several depth measurements taken throughout the habitat unit.

When to record: every habitat unit

Riffle Crest Depth (cm)

Definition:
Vertical distance from the substrate to the water surface at the deepest point in the riffle crest. The riffle crest is the shallowest continuous line (usually not straight) across the channel where the water surface becomes continuously riffled in the transition area between a riffle (or a run or cascade) and a pool (or glide) (Armantrout 1998); think of it as the last place water would flow out of the pool if the riffle ran dry.

How to estimate:
When the observer reaches the upstream end of a riffle (or a run or cascade) leading into a pool (or glide), they use the wading rod to measure the deepest point in the riffle crest. Record the depth in the RCD column for the riffle habitat row.

When to record: at the upstream end of any riffle, run, or cascade leading into a pool or glide

Dominant and Subdominant Substrate (1-9)

Definitions:
Dominant Substrate: size class of stream bed material that covers the greatest amount of surface area within the wetted channel of the habitat unit
Subdominant Substrate: size class of stream bed material that covers the 2nd greatest amount of surface area within the wetted channel of the habitat unit

How to estimate:
The following size classes are used to categorize substrates*. The substrate 'Number' is entered into the dominant and subdominant substrate columns on the datasheet.

Type	Number	Size (mm)	Description
Organic Matter	1		dead leaves, detritus, etc. – **not live plants**
Clay	2		sticky, holds form when rolled into a ball
Silt	3		slippery, does not hold form when rolled into a ball
Sand	4	silt – 2	grainy, does not hold form when rolled into ball
Small Gravel	5	3-16	sand to thumbnail
Large Gravel	6	17-64	thumbnail to fist
Cobble	7	65-256	fist to head
Boulder	8	>256	larger than head
Bedrock	9		solid rock, parent material, may extend into bank

** these size classes are based on the modified Wentworth scale*

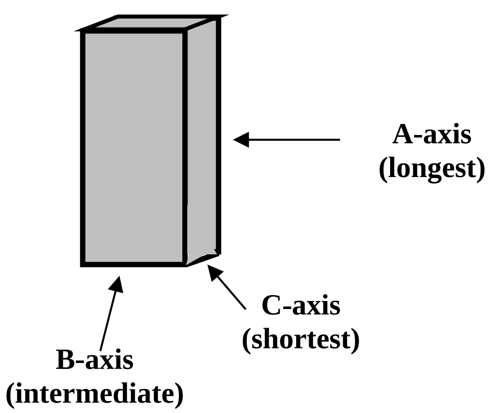
As the observer walks through the unit they scan the substrate. When they reach the upstream end of the unit they stop, turn to face the unit, and determine the dominant and subdominant substrate classes.

Estimate substrate size along the intermediate axis (b-axis). The b-axis is not the longest or shortest axis, but the intermediate length axis (see below). It is the axis that determines what size sieve the particle could pass through. Remember that your eyes are naturally drawn to larger size substrates. Be careful not to bias your estimate by focusing on the large size substrate.

Some units will contain a mixture of particle sizes. Consult with the recorder and use your best professional judgment to choose the dominant and subdominant sizes.

In units where the substrate is covered in moss, algae, or macrophytes classify the underlying substrate and make note of the plant growth in the comments. Only call organic substrate where there is dead and down leaves or other detritus covering the bottom of the unit.

When to record: every habitat unit



Rosgen Channel Type (A-G)

Definitions:
Stream channel classification system described in Rosgen (1996) based on entrenchment, width/depth ratio, sinuosity, and percent slope

How to Measure:
Before the crew begins the inventory they should make the measurements described below to determine the channel type. Channel types are based on the following channel characteristics:

	A	B	C	D	E	F	G
Entrenchment	< 1.4	1.4 – 2.2	> 2.2	n/a	> 2.2	< 1.4	< 1.4
W/D Ratio	< 12	> 12	> 12	> 40	< 12	> 12	< 12
Sinuosity	1 – 1.2	> 1.2	>1.2	n/a	> 1.5	> 1.2	> 1.2
Slope (%)	4 – 9.9	2 – 3.9	< 2	< 4	< 2	< 2	2 – 3.9

Although we record channel type for every unit, it was designed to describe a reach of stream. Our main objective here is to locate changes between channel types, which could either be abrupt (such as change from a B to a G near a road crossing) or less obvious transitional areas (such as a natural transition from a B to an A channel as you move upstream). If you think channel type may have changed take the time to make the calculations listed below to determine the channel type for the reach you are entering.

Full channel type descriptions and how to measure each of the channel characteristics in the table above can be found in Rosgen (1998). Never perform measurements in a pool, always attempt to find a run or deep riffle with well-defined bankfull indicators to perform measurements. A summary of each is listed below:

Entrenchment (page 31 & 32 in Rosgen field guide):

- locate suitable riffle or run area for bankfull measurement (page 24-25 in Rosgen field guide)
- measure the bankfull width the maximum bankfull depth
- stretch a tape across the channel at 2x the maximum bankfull depth (this is the flood prone area)
- divide the flood prone area width by the bankfull width to determine entrenchment ratio

Width to Depth Ratio (page 32 in Rosgen field guide):

- locate suitable riffle or run area for bankfull measurement (page 24-25 in Rosgen field guide)
- measure the bankfull width and the maximum bankfull depth
- divide bankfull width by depth to determine width to depth ratio

Sinuosity (need aerial photo to determine)

Slope (page 37 in Rosgen field guide):

- Measure riffle to riffle gradient using clinometer

When to measure: every paired fastwater habitat unit*

* record for every fastwater paired unit, but remember this is describing a reach characteristic – see above

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology Books, Pagosa Springs, Colorado.

Rosgen, D.L., and L. Silvey. 1998 Field Guide for Stream Classification, Wildland Hydrology Books, Pagosa Springs, Colorado.

Percent Fines (%)

Definition:
Percent of the total surface area of the stream bed in the wetted area of the habitat unit that consists of sand, silt, or clay substrate particles (i.e. particles < 2 mm diameter).

How to estimate:
As the observer walks through the habitat unit they note the amount of sand, silt, and clay in the habitat unit. When they reach the upstream end of the unit, they stop, turn to face the unit and estimate the amount of the total surface area within the wetted channel that consists of sand, silt, or clay.

Where to estimate: every habitat unit

Large Wood (1-4 and rootwad)

Definition:
Count of dead and down wood within the bankfull channel of a habitat unit

How to estimate:
The recorder classifies and counts LW as they walk through the habitat unit. LW counts are grouped by the size classes listed below:

Category	Length (m)	Diameter (cm)	Description
1	1-5	10-55	short, skinny
2	1-5	>55	short, fat
3	>5	10-55	long, skinny
4	>5	>55	long, fat
RW	rootwad	rootwad	roots on dead and down tree

Only count woody debris that is:

- > 1.0 m in length and > 10.0 cm in diameter
- within the bankfull channel
- fallen, not standing dead

- Count rootwads separately from attached pieces of LW
- Estimate the diameter of LW at the widest end of the piece
- A piece that is forked, but is still joined counts as only one piece of LW
- Only count each piece one time, do not count a piece that is in two habitat units twice
- Enter the total count for each size category into the appropriate column on the datasheet

Where to estimate: every habitat unit

Actual Width (m)

Definition:
Average wetted width of the habitat unit as measured with 50 m tape, used to calculate stream area. Wetted width is the distance from the edge of the water on one side of the main channel to the edge of the water on the opposite side of the main channel.

How to measure:
Use a meter tape to measure the wetted width of the stream in at least three locations. Average the measurements to obtain the average wetted width.

Where to measure: paired sample habitat units

Photo #

Definition:
Photograph of habitat unit or crossing feature.

How to measure:
Take photo facing upstream with observer holding wading rod in picture. Be sure to get entire width (and length if possible) of habitat unit or crossing feature in the photo. Record photo number shown on digital camera.

Where to measure: paired sample riffles, runs, or cascades and any crossing features encountered

Features

Definition: points on a stream that could potentially serve as landmarks, may be natural or manmade

How to measure: record the distance to the upstream end of a feature; record distance of **all features** (both stream and crossing features) in the regular habitat datasheet; also record additional measurements for crossing features in the crossing datasheet and take a photograph of all crossing features

Where to record: wherever found

Channel Feature	Abbreviation	What to Record
Waterfall[1]	**FALL**	Distance, estimated height
Tributary	**TRIB**	Distance, average wetted width, into main channel on left or right (as facing upstream)
Side channel[2]	**SCH**	Distance, average wetted width, whether it is flowing into or out of main channel on left or right (as facing upstream)
Braid[3]	**BRD**	Distance at start and distance at end; continue with normal inventory up channel with greatest discharge
Seep (Spring)	**SEEP**	Distance, left or right bank (as facing upstream), size, coloration
Landslide	**SLID**	Distance, left or right bank (as facing upstream), estimated size
Other	**OTR**	Distance, description of feature, *example:* found water intake pipe going to house here; old burned out shack on side of stream; Big Gap campground on left; alligator slide here, etc.

1 must be vertical with water falling through air to be a waterfall and not a cascade, do not record unless >1m high
2 two channels, continue with normal inventory up channel with most volume
3 three or more channels intertwined, continue with normal inventory up channel with most volume

Crossing Feature	Abbreviation	What to Record*
Bridge	**BRG**	Distance, width, height, road or trail name and type (gravel, paved, dirt, horse, ATV, etc.), photo
Ford	**FORD**	Distance, road or trail name and type (gravel, paved, dirt, etc.), photo
Dam	**DAM**	Distance, type, condition, estimated height, dam use, name of road or trail, if applicable; include beaver dams, photo
Culvert	**V**	Distance, road or trail name, type, # of outlets, diameter/width, height, material, perch (distance from top of water to bottom lip of culvert, natural substrate (present or absent through length), photo

* photograph all crossing features with person and wading rod for scale, record 'Y' in 'Photo' column

We cannot stress enough the importance of fully and accurately describing features. This means getting out a quadrangle map and finding road, trail, and tributary names and recording them in 'Comments' and taking the time to describe the location of features in relation to landmarks found on quadrangle maps.

Take photos of all crossing features!

Section 3: Wrapping Up

End the inventory where:

- Forest Service property ends
- stream is dry for more than 1000 m
- stream channel is < 1.0 m wide for more than 500 m

Record the following in the Comments:

- Time and date
- Reason for ending the inventory
- Detailed written description of location using landmarks for reference

** be sure the header information is completed – GPS, etc.**

When you return to home base:

- Immediately download the data and check file to be sure all data downloaded
- Check header information to be sure it is complete
- Note in all files if more than one file was used during the inventory
- Save to the computer and create a backup copy
- Document any photographs
- If using paper, make a photocopy of the data and store in secure location
- Record on master list that inventory is complete, with data and names of crewmembers

Section 4: Summary

Before starting, determine interval, select random number, fill in header information

Record for every habitat unit:

- NHD_ID
- Unit Type
- Unit Number
- Distance
- Estimated Width
- Maximum Depth
- Average Depth
- Dominant Substrate
- Subdominant Substrate
- Percent Fines
- Large Wood

Record for every riffle, run, or cascade leading into a pool or glide:

- Riffle Crest Depth

Record for every paired sample pool and riffle:

- Measured Width

Record features and full feature descriptions wherever they are encountered. Photograph all crossings!

When end of inventory is reached, record reason for ending, date, time, and GPS coordinates.

Appendix: Field Guide, Random Numbers Table, Equipment Checklist

Record for every habitat unit:

NHD_ID: NHD stream reach number from provided maps
Unit Type: pool, riffle, run, cascade, glide, feature (see below)
Unit Number: group pools & glides; group riffles, runs, cascades
Distance: (m) at upstream end of unit
Estimated Width: (m) visual estimate of average wetted width
Maximum Depth: (cm) deepest spot in unit
Average Depth: (cm) average depth of unit
Dominant Substrate: (1-9) covers greatest amount of surface area in unit
Subdominant Substrate: (1-9) covers 2nd most surface area in unit
Percent Fines: (%) percent of bottom consisting of sand, silt, or clay
Large Wood: (1-4, RW) count of dead and down wood in the bankfull channel

Record for every riffle, run, or cascade leading into a pool or glide:

Riffle Crest Depth: (cm) deepest spot in hydraulic control between riffle type habitat and pool type habitat

Record for paired sample pools:

Measured Width: (m) measurement of average wetted width

Record for paired sample riffles:

Measured Width: (m) measurement of average wetted width
Channel Width: (m) measurement of bankfull channel width
Riparian Width: (L&R) (m) measurement of floodplain
Photo # : picture of habitat unit or crossing feature

Unit Types

Riffle (R) fast water, turbulent, gradient <12%; includes rapids, chutes, and sheets if gradient <12%
Cascade (C) fast water, turbulent, gradient $\geq$12%, includes sheets and chutes if gradient $\geq$12%
Run (RN) fast water, little to no turbulence, gradient <12%, flat bottom profile, deeper than riffles
Pool (P) slow water, may or may not be turbulent, gradient <1%, includes dammed, scour, and plunge pools
Glide (G) slow water, no surface turbulence, gradient <1%, shallow with little flow and flat bottom profile
Underground (UNGR) distance at upstream end, why dry

Features

Waterfall (FALL) distance, height
Tributary (TRIB) distance, width, in on L or R
Side Channel (SCH) distance, width, in or out on L or R
Braid (BRD) distance at downstream and upstream ends
Seep or Spring (SEEP) distance, on left or right, amount of flow
Landslide (SLID) distance, L or R, est. size and cause
Other (OTR) record distance, describe feature in comments

Crossing Features: Photograph and record the following:
Bridge (BRG) distance, height, width, road or trail name & type
Dam (DAM) distance, type, est. height, road or trail name &type
Ford (FORD) distance, road or trail name & type
Culvert (V) distance, type (pipe, box, open box, arch, open arch), size, material, natural substrate, perch (top of water to culvert) road or trail name

Substrates

1. **Organic Matter**, dead leaves detritus, etc., not living plants
2. **Clay**, sticky, holds form when balled
3. **Silt**, slick, does not hold form when balled
4. **Sand**, >silt-2mm, gritty, doesn't hold form
5. **Small Gravel**,3-16mm, sand to thumbnail
6. **Large Gravel**, 17-64mm, thumbnail to fist
7. **Cobble**, 65-256mm, fist to head
8. **Boulder**, >256, > head
9. **Bedrock**, solid parent material

Large Wood

1. <5m long, 10-55cm diameter
2. <5m long, >55cm diameter
3. >5m long, 10-55cm diameter
4. >5m long, >55cm diameter

RW: rootwad – count separately from attached LW, record in comments
do not record woody debris <10cm diameter, <1m length

End inventory

Where stream is less than 1.0 m wide for > 500 m, or channel runs dry for > 1.0 km, or where boundary is reached. Comment on why inventory was ended. Record time of day, detailed description of location, and GPS coordinates at endpoint, and be sure all header info is filled in on datasheets.

Random numbers for measuring every 5th unit

4	3	5	1	5	1	2	5	2	3
2	5	2	5	2	2	1	5	4	1
3	2	5	1	2	1	3	1	5	3
5	4	1	5	1	3	5	4	2	5
4	2	2	5	2	2	5	5	2	1
4	2	5	2	2	4	5	5	5	2
3	5	4	1	5	1	4	1	3	3
1	4	2	2	1	4	3	1	5	3
5	4	3	3	2	4	1	2	5	1
4	4	1	1	3	5	1	5	5	4

Random numbers for measuring every 10th unit

3	7	10	5	1	2	2	7	10	6
4	2	3	8	9	2	4	4	6	9
3	3	8	4	3	9	9	7	5	5
1	3	5	5	2	6	5	2	2	6
3	7	8	6	3	8	8	5	2	10
10	9	6	9	4	3	10	7	2	10
6	10	5	4	8	10	4	1	4	10
4	3	4	3	2	3	4	4	3	7
5	1	7	9	7	3	10	7	10	3
9	6	8	6	2	2	1	9	10	5

Choose a new random number at the beginning of each stream inventory
Use the number for the entire stream
Use the first table for streams < 1.0 km long, the second table for streams >1.0 km long

Equipment Checklist

hipchain
extra string for hipchain
wading rod
50 m tape measure
datalogger
backup battery for datalogger
GPS unit
camera
backpack
pencils
flagging
markers
waterproof backup datasheets
BVET manual
topographic maps
NHD_ID maps
water
water filter
lunch
first aid kit
radio/cell phone
toilet paper
felt bottom wading boots
raingear

Remember the following for the start of each new stream or reach:

- Determine measuring interval
- Select a random number
- Fill in header information completely

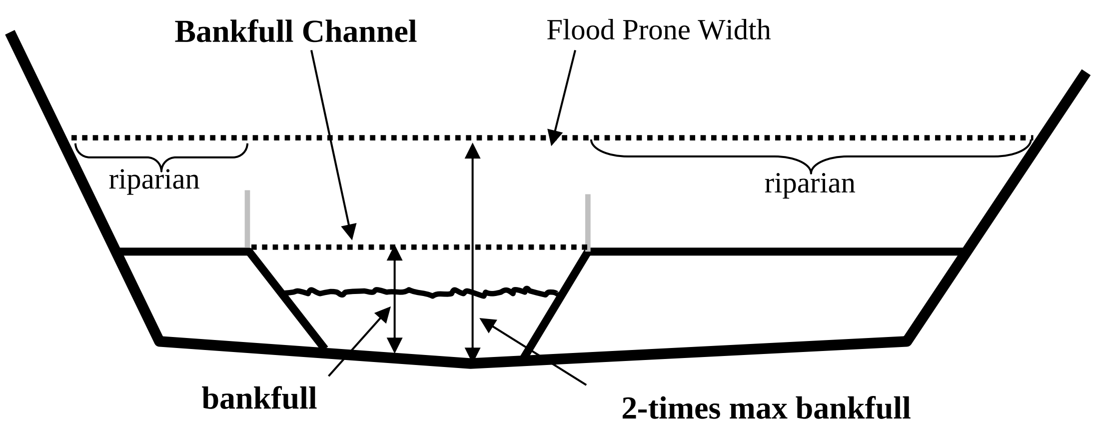
Rosgen Measurements

All measurements should be made across a transect in an area of uniform flow, specifically riffle or run sections with few irregularities in cross-sectional shape. **Avoid** areas influenced by culverts, bridges, tributaries, side-channels, etc.

- What is the **entrenchment ratio**?
  - Entrenchment ratio = flood prone width / bankfull width
  - Floodprone width = width at two-times maximum bankfull depth

- What is the **width/depth ratio**?
  - Width/depth ratio = bankfull width / average bankfull depth
  - Be sure to use same units of measure (centimeters) for width and depth
  - Measure *bankfull* depth (**not** *water* depth) at several locations across transect to obtain average bankfull depth

- What is the **gradient**?
  - Measure riffle to riffle slope (%) with clinometer



Rosgen Worksheet

A. Bankfull Channel Width (m) _____

B. Maximum Bankfull Depth (cm) _____ *2 = _____

C. Average Bankfull Depth (cm) _____

D. Right Riparian Width (m) _____

E. Left Riparian Width (m) _____

F. Gradient (%) _____

Entrenchment Ratio = (A+D+E)/A

(_____ + _____ + _____) / _____ = _____

Width Depth Ratio = (100*A)/C

(100* _____) / _____ = _____

	A	**B**	**C**	**D**	**E**	**F**	**G**
Entrench. ratio	< 1.4	1.4 – 2.2	> 2.2	n/a	> 2.2	< 1.4	< 1.4
W/D ratio	< 12	> 12	> 12	> 40	< 12	> 12	< 12
Gradient (%)	4 – 9.9	2 – 3.9	< 2	< 4	< 2	< 2	2 – 3.9

*these are the dominant ranges, values may be slightly outside these ranges

Appendix B: 2014 vs. 2019 Photo Comparisons

2014

2019

Section D: Gabion retaining wall at 1,392 m.

2014

2019

Section D: Bridge at 5,923 m.

2014

2019

Section E: Pool at 571 m (looking downstream in 2014; looking upstream in 2019).

2014

2019

Section E: Bridge at 1,647 m.

2014

2019

Section E: Bridge at 2,379 m.

2014

2019

Section E: Restoration structure at 2,385 m.

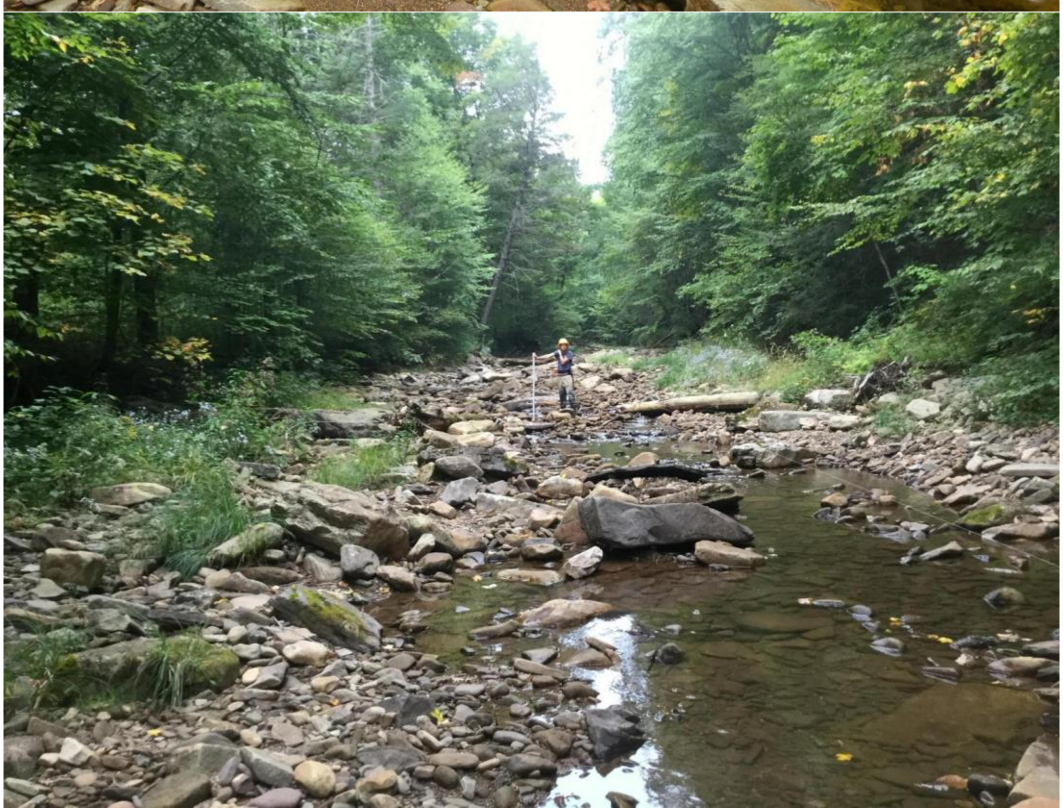
2014

2019

Section E: Restoration structure at 2,418 m.

2014

2019



Section E: Restoration structure at 2,601 m.

2014

2019

Section E: Restoration structure at 2,630 m.

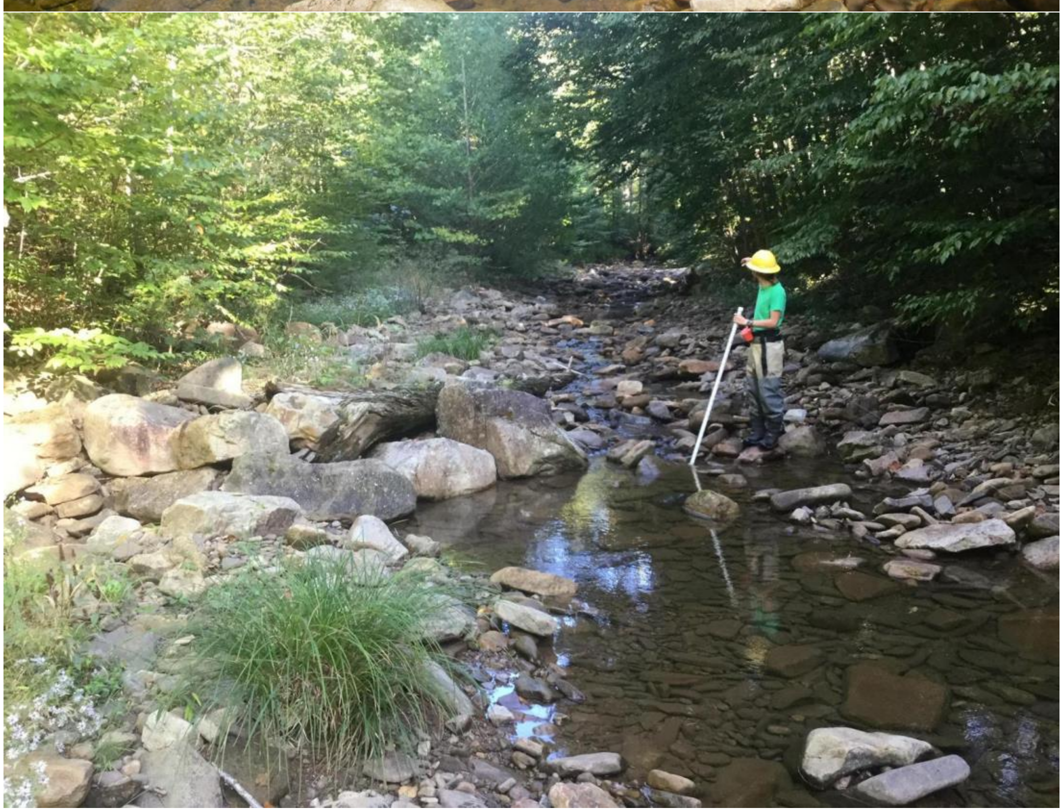
2014

2019

Section E: Restoration structure at 2,722 m.

2014

2019



Section E: Restoration structure at 2,750 m.

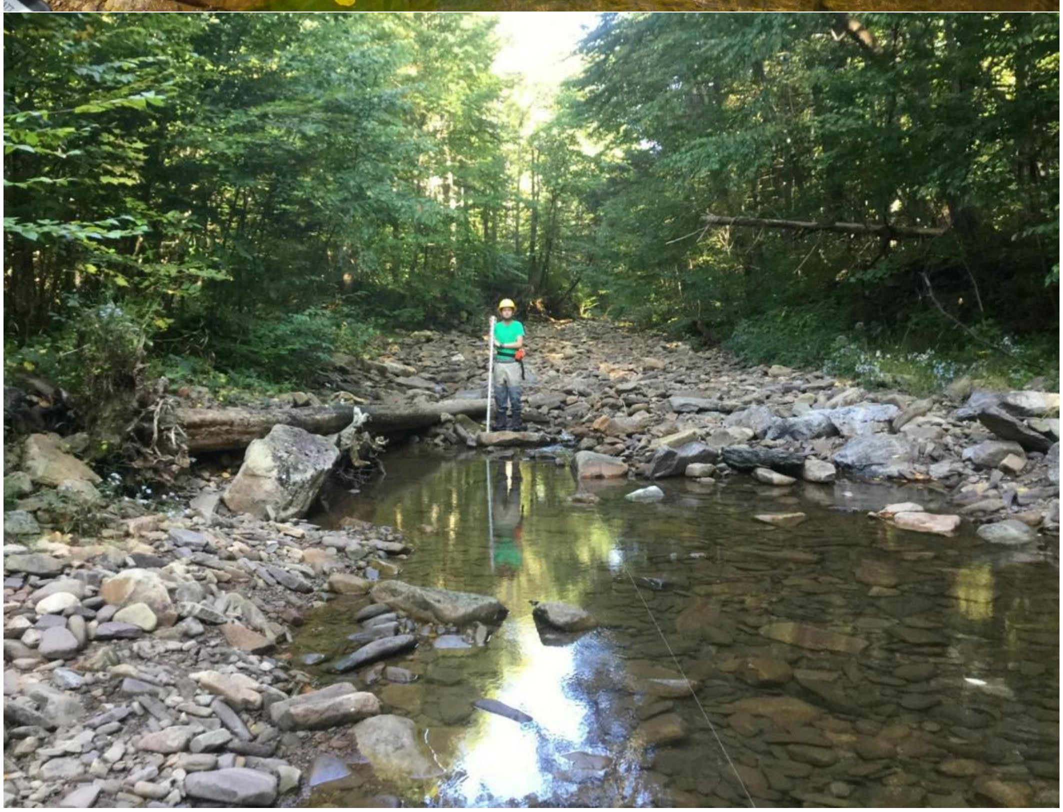
2014

2019

Section E: Restoration structure at 2,775 m.

2014

2019



Section E: Restoration structure at 2,813 m.

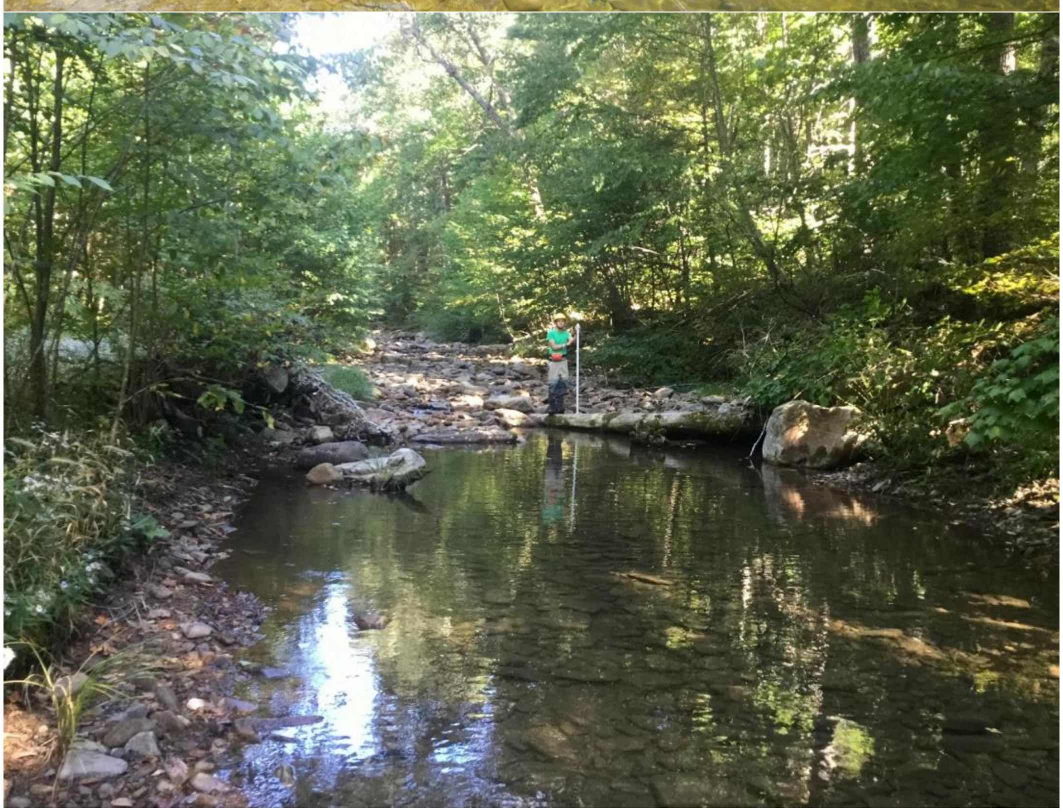
2014

2019

Section E: Restoration structure at 3,164 m.

2014

2019



Section E: Restoration structure at 3,252 m.

2014

2019

Section E: Restoration structure at 3,287 m.

2014

2019

Section E: Restoration structure at 3,319 m.

2014

2019

Section E: Restoration structure at 3,342 m.

2014

2019

Section E: Restoration structure at 3,383 m.

2014

2019

Section E: Restoration structure at 3,412 m.

2014

2019

Section E: Restoration structure at 4,110 m.

2014

2019

Section E: Restoration structure at 4,147 m.

2014

2019

Section E: Restoration structure at 4,181 m.

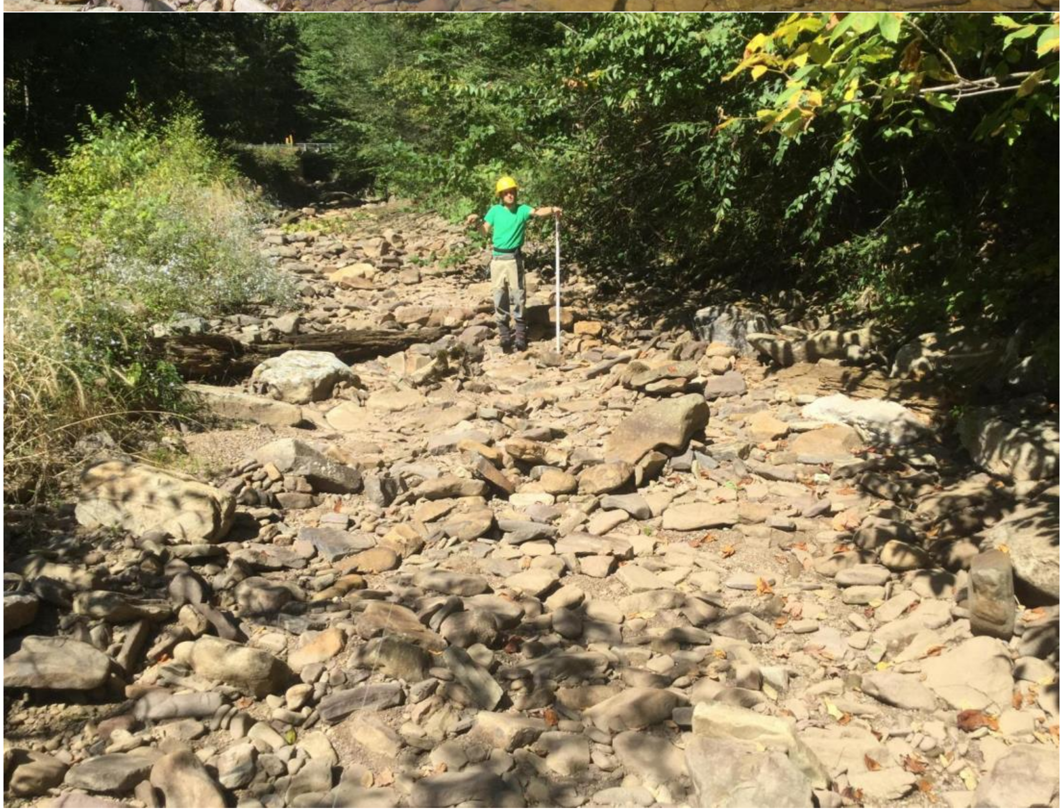
2014

2019

Section E: Restoration structure at 4,221 m.

2014

2019



Section E: Restoration structure at 4,443 m.

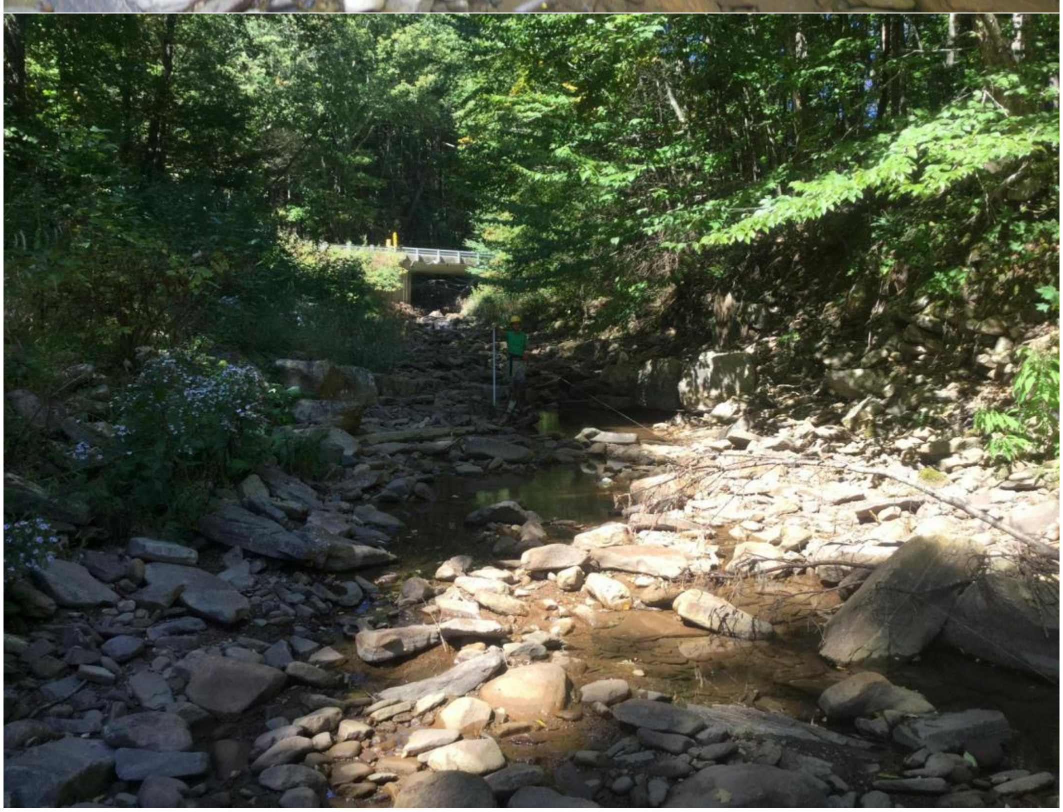
2014

2019

Section E: Restoration structure at 4,475 m.

2014

2019



Section E: Restoration structure at 4,505 m.

2014

2019

Section E: Gabion wall at 4,519 m.

2014

2019

Section E: Restoration structure at 4,547 m.

2014

2019

Section E: Restoration structure at 4,582 m.

2014

2019

Section E: Restoration structure at 4,629 m.

2014

2019

Section E: Restoration structure at 4,725 m.

2014

2019

Section E: Restoration structure at 4,752 m.

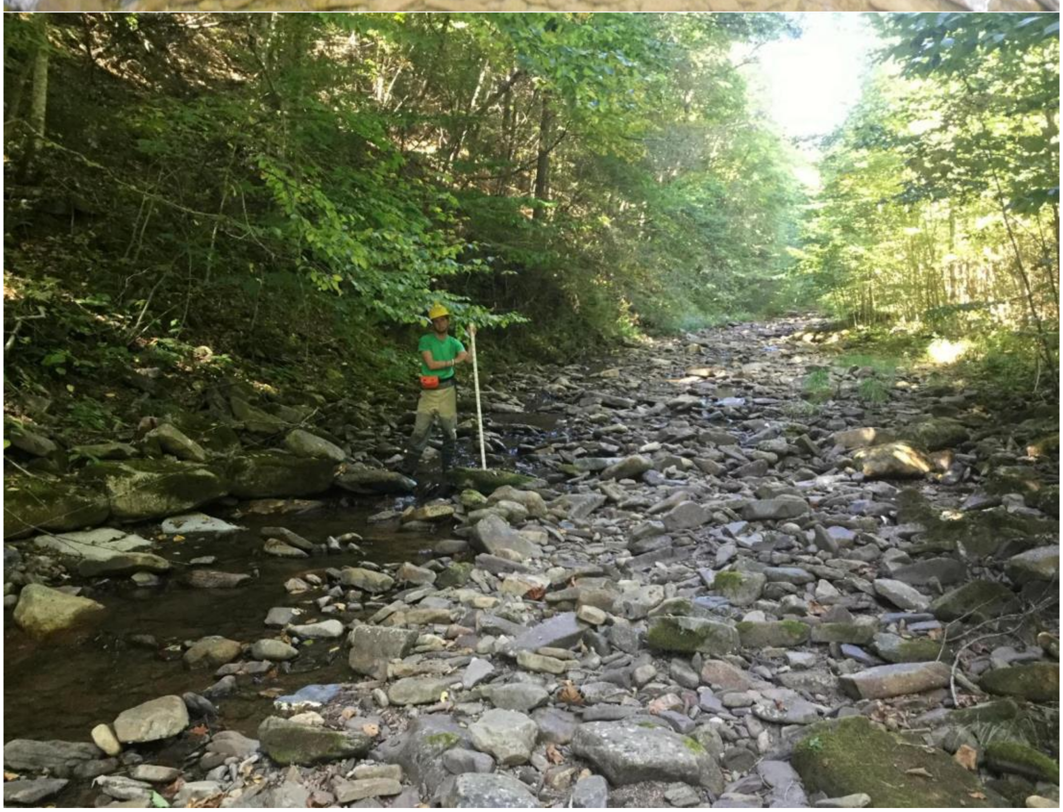
2014

2019

Section E: Restoration structure at 4,782 m.

2014

2019



Section E: Restoration structure at 4,809 m.

2014

2019

Section E: Restoration structure at 5,015 m.

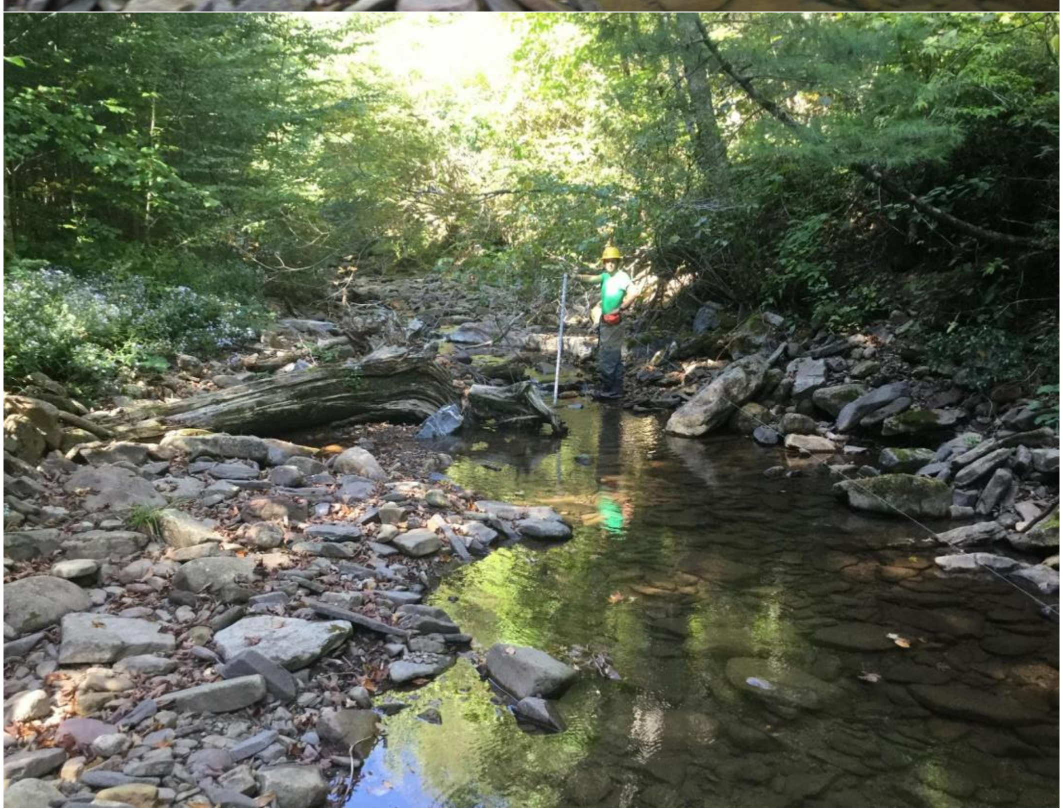
2014

2019

Section E: Restoration structure at 5,058 m.

2014

2019



Section E: Restoration structure at 5,109 m.

2014

2019

Section E: Restoration structure at 5,160 m.